Operational Monitoring Plan Development

A guide to strengthening operational monitoring practices in small- to medium-sized water supplies

World Health Organization
Regional Office for South-East Asia

Operational Monitoring Plan Development

A guide to strengthening operational monitoring practices in small- to medium-sized water supplies

Operational monitoring plan development: a guide to strengthening operational monitoring practices in small-to medium-sized water supplies.

ISBN: 978-92-9022-537-9

Suggested citation. Operational monitoring plan development: a guide to strengthening operational monitoring practices in small-to medium-sized water supplies. New Delhi: World Health Organization, Regional Office for South-East Asia; 2017. Licence: CC BY-NC-SA 3.0 IGO.

Cataloguing-in-Publication (CIP) data. CIP data are available at http://apps.who.int/iris.

Contents

Acronyms and Abbreviations

<	less than
>	greater than
HWTS	household water treatment and safe storage
m^3/day	cubic meters per day
mg/L	milligram per litre
min.mg/L	minutes per milligram per litre
NTU	nephelometric turbidity unit
OMP	Operational Monitoring Plan
SEARO	South-East Asia Regional Office
SOP	standard operating procedure
WHO	World Health Organization
WSP	Water Safety Plan

Acknowledgements

This guide and the associated training materials were prepared by Rory Moses McKeown. Valuable technical input was provided by Mathew Whitelaw, Jarrah Feather and Matthew Turner of East Gippsland Water, Australia and Angella Rinehold, World Health Organization Consultant, U.S.A. Darryl Jackson, Consultant, Australia, provided technical review and David Sutherland, World Health Organization, India, editorial review.

WHO acknowledges and appreciates the financial support from the Australian Government's Department for Foreign Affairs and Trade.

Australian Government
Department of Foreign Affairs and Trade

Australian Aid

Image credits:

Cover page: Operational monitoring plan development training: Wangdue water supply system, Bhutan (R. M. McKeown, 2014); Page 9: A. Rinehold; D. Jackson; Part 2 cover page: Rakizampa source water off-take, Wangdue water supply system, Bhutan (R. M. McKeown, 2014); Page 39: Shutterstock.com; Page 47: Shutterstock.com; Case study cover page: Wangdue water treatment facility, Bhutan (R. M. McKeown, 2014).

Introduction

Water safety plans (WSPs) are widely regarded as the most effective means to manage drinking-water safety. This preventative, holistic approach is increasingly being adopted throughout the world as best practice for drinking-water quality risk assessment and management. Operational monitoring is a core component of the WSP framework to ensure that the control measures in place to manage drinking-water quality risks are working effectively. Strengthening operational monitoring capabilities through supportinag programmes is important for the development of local capacity for sustainable WSP implementation.

What is the aim of this guide?

This guide aims to provide stepwise instructions on how to develop operational monitoring plans (OMPs) for small- to medium-sized organized water supplies in lower resource settings. It is intended to act as a supporting programme for staff development and training under the WSP framework[1]. The guide is intended to support the development of a basic OMP from first principles for organized water supply systems with conventional water treatment capabilities. The guide supports an operational monitoring development training programme, with the corresponding training presentation available to download from the World Health Organization's (WHO's) South-East Asia Regional Office (SEARO) website[2].

For whom is the guide intended?

This guide is intended for individuals responsible for WSP development and implementation within small- to medium-sized organized water supply systems. The material contained within this guide is also relevant for operational-level personnel (including those with responsibility for performing operational monitoring activities), water suppliers, as well as representatives from public health, local government, non-governmental organizations and any other individuals supporting water safety planning activities.

How is the guide structured?

The guide is presented in two parts:

Part 1. Principles of Operational Monitoring: Describes the key principles of operational monitoring, alongside the types of operational monitoring that may be performed and the information required within an OMP.

Part 2. Operational Monitoring Plan Development: Describes the stepwise development of an OMP for a water supply system, including the source, water treatment, intermediate storage, distribution and household. For illustration purposes, practical guidance is provided using a specimen water supply system considered to be representative of a conventional small- to medium-sized supply in a lower resource setting. This template may be used to develop system-specific OMPs for individual water supply systems.

Information contained within this guide provides an overview of key information to assist with the development of OMPs; for further information, please refer to the *Water Safety Plan Manual*[1].

1 Bartram et al. (2009). Water safety plan manual: Step-by-step risk management for drinking-water suppliers. Geneva, Switzerland.
2 http://www.searo.who.int/entity/water_sanitation/documents/WSP_Training_Modules/en/.

Part 1. Principles of Operational Monitoring

Describes key operational monitoring principles to assist with the development of an effective operational monitoring plan

1.1 What is operational monitoring?

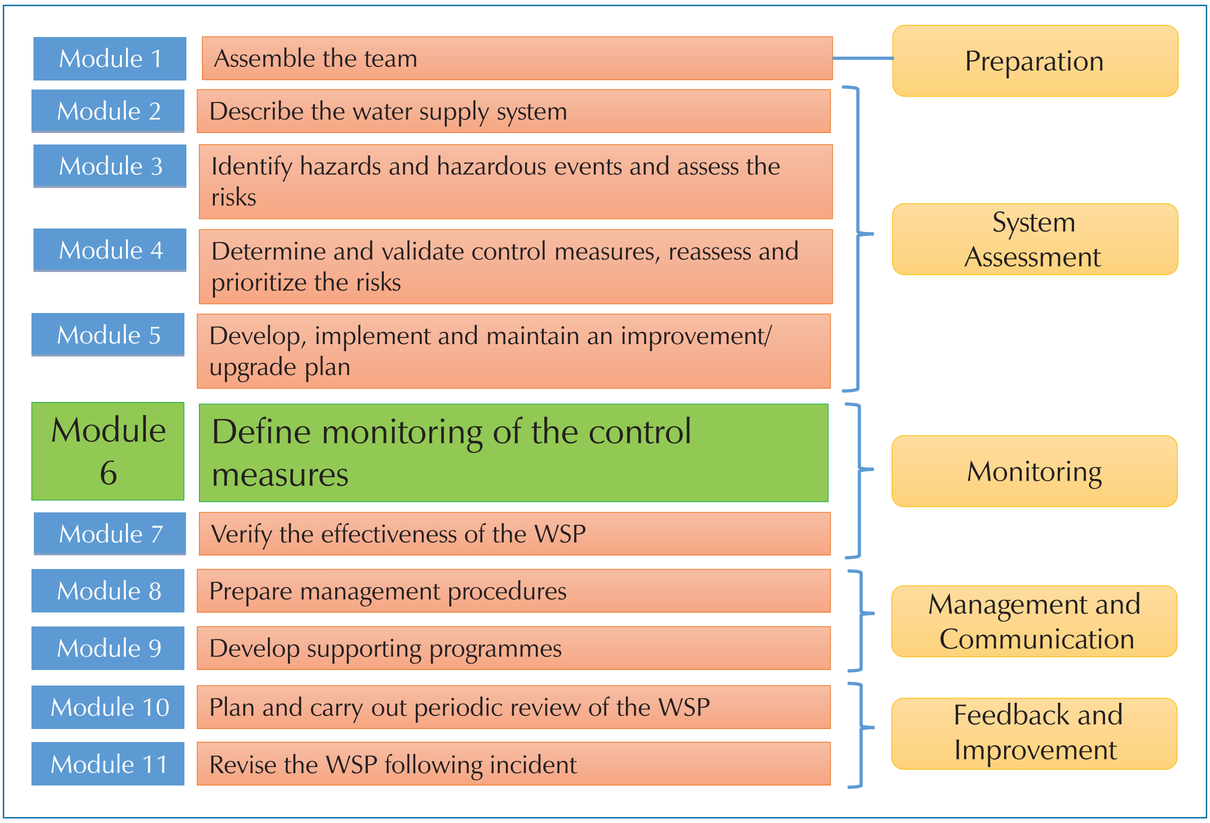
Operational monitoring involves performing simple, routine checks to confirm that a water supply system is operating within acceptable limits. Operational monitoring is a key component of a WSP, as shown in Figure 1.

Operational monitoring checks the performance of control measures, that is, the measures in place within a water supply system that prevent or eliminate a water safety hazard, or reduce it to an acceptable level. Operational monitoring enables quick confirmation that the controls measures within a water supply system are working effectively to minimize the risk of unsafe drinking-water supply[3].

Each operational monitoring check should have a critical limit assigned to it (see Section 1.3.2), that is, the point where a control measure is operating outside of an acceptable limit and a potential water quality risk exists.

If a problem is identified through routine operational monitoring, timely operational action must then be taken to correct the issue prior to the supply of unsafe drinking-water; this is referred to as corrective action (see Section 1.3.3). Operational monitoring, appropriate critical limits and effective corrective actions work together to help minimize the risk of unsafe drinking-water supply.

Figure 1. *Modules to develop and implement a WSP, including operational monitoring (as part of Module 6) (adapted[1])*



An operational monitoring plan or OMP is a document, which should clearly describe the operational monitoring that must be performed to ensure that the control measures are working

3 Note: Operational monitoring is separate to compliance monitoring, which involves the testing of drinking-water to ensure that it meets water quality standards; compliance monitoring is part of WSP verification (Module 7), to ensure that the WSP, as a whole, is functioning effectively to deliver safe drinking-water.

effectively. The OMP should describe the type, the location and the frequency of operational monitoring to be performed, alongside who is responsible for performing the monitoring, how the monitoring will be performed, as well as details of the corresponding critical limits and corrective actions (see Section 1.3).

As control measures are uniquely identified for each individual water supply system, an OMP must also be tailored specifically to an individual system. When developing an OMP, control measures must firstly be identified through the WSP process (Module 4; Figure 1) so that effective operational monitoring of each specific control measure may be defined (Module 6; Figure 1).

1.2 What type of checks should be performed for operational monitoring?

Operational monitoring should be:

(1) simple – easy to perform;

(2) rapid – quick to carry out, providing fast, reliable results; and

(3) routine – easy to incorporate into normal operational duties.

Operational monitoring may be either:

(4) measurable – that is, water quality tests (for example, testing the turbidity levels at the water treatment plant); or

(5) visual – that is, an observation (for example, visually confirming that the security gate around a water storage tank is locked).

Rapid, reliable results are necessary for operational monitoring so that timely corrective action may be taken to restore the effectiveness of the control measure. For example, measuring the level of chlorine in water is an effective water quality testing parameter for operational monitoring – a chlorine test on the treated water can indicate within minutes that the chlorine disinfection process (i.e. the addition of chlorine to inactivate or kill microorganisms present in the water; also referred to as chlorination) is not optimal, and that corrective action is immediately required to prevent unsafe drinking-water from being supplied to consumers. However, testing for the presence of harmful microorganisms is less effective for operational monitoring – results for microbial testing take time (for example, typically between 16 to 72 hours) and during this time, unsafe water may be supplied to consumers before the problem is detected and appropriate corrective action may be applied[4]. Table 1 describes basic water quality tests that are suitable for operational monitoring.

At a minimum, it is recommended that a basic OMP should test for the parameters presented in Table 1. Depending on the water quality risks identified for a particular water supply system, as well as the resources available within that setting, additional water quality parameters may be considered for inclusion in the OMP, including, for example, water temperature, colour, conductivity, salinity, filter head-loss and water pressure.

4 For this reason, microbiological testing is more suited to compliance monitoring as part of verification.

Table 1. *Examples of basic water quality testing parameters used in operational monitoring*

Water quality parameter	Description	Operational monitoring data indicates	Common method(s) of measurement
Turbidity	Turbidity is caused by the presence of organic and inorganic particles in water (e.g. minerals, microorganisms) giving water a cloudy appearance	• Potentially hazardous events in the water supply system (e.g. poor source water quality, failure of the water treatment process, loss of distribution network integrity, such as water main leak/burst, illegal connection) • Potential for reduced effectiveness of disinfection • Potential for consumer acceptability issues (e.g. taste, odour, appearance)	• Turbidity tube • Turbidity meter
Chlorine **(if chlorination is practised)**	Chlorine is added to drinking-water to kill or inactivate harmful microorganisms and to protect the water from microbial recontamination during delivery to the consumer	• The effectiveness of disinfection • The degree of residual protection from recontamination by microorganisms during distribution[5] • Potential hazardous events in the water supply system (e.g. increase in the presence of organic/inorganic material in the water[6], over-/under-dose of chlorine, loss of distribution network integrity) • Potential for consumer acceptability issues (e.g. chlorine taste, odour)	• Disposable chlorine test strip • Comparator test kit • Chlorine meter
pH **(if chlorination and/or chemical coagulation is practiced)**	pH indicates the acidity or alkalinity of water	• Potential for reduced effectiveness of a water treatment process (e.g. coagulation/flocculation, chlorine disinfection) • Potential hazardous events in the water supply system (e.g. discharges of waste in the catchment, over-/under-dose of water treatment chemical)	• Disposable pH test strips • Comparator test kit • pH meter

Table 2 presents examples of typical hazards, hazardous events, control measures and corresponding operational monitoring parameters

Table 2. *Examples of typical hazards, hazardous events, control measures and corresponding operational monitoring at each step within a water supply system*

Process step	Hazardous event/ Source of hazard(s)	Control measure	Operational monitoring
Catchment	Stock defecating in the source water (M, P)	**Fencing to prevent stock access to river**	Integrity of stock exclusion fence (V)
	Raw water turbidity spike following run-off from rainfall (M, P)	**Sedimentation tank at raw water off-take**	Water turbidity post-sedimentation (Ms)
Water treatment plant	Impairment of treatment process due to vandalism (M, C, P)	**Security fencing**	Integrity of security fence (V)
	Reduced effectiveness of disinfection due to high raw water turbidity following rain-fall event (M)	**Filtration**	Filtered water turbidity (Ms)
Intermediate storage tank	Regrowth of microorganisms on tank-water interface during treated water storage (M)	**Maintenance of residual chlorine concentration**	Residual chlorine concentration in tank water (Ms)
	Accumulation of sediment in tank over time (M, P)	**Tank cleaning programme**	Tank outlet water turbidity (Ms)

Process step	Hazardous event/ Source of hazard(s)	Control measure	Operational monitoring
Distribution system	Regrowth of microorganisms on pipe wall during distribution (M)	**Secondary (or booster) chlorination**	Residual chlorine concentration in distribution system (Ms)
	Suspension of sediment in distribution pipes following abnormal flow event (M, P)	**Water main maintenance/ cleaning programme**	Distribution system water turbidity (Ms)
Household level	Contamination of water through insanitary household treatment/ storage practices (M)	**Household water treatment and safe storage awareness programme**	Observation of household water treatment and safe storage practices (V)
	Contamination of water through the use of inappropriate plumbing materials (C)	**Consumer plumbing inspection programme**	Inspection of consumer internal plumbing (V)

M – microbial; C – chemical; P – physical; V – visual; Ms – measurable.

Operational monitoring is ideally preventative, that is, intended to provide an early indication that a control measure is failing, or about to fail, so that timely corrective action may be taken before unsafe water is supplied to the consumer. For example, if the limit of acceptability for filtered water turbidity is defined as 5 NTU, preventative operational monitoring may set the critical limit to 3 NTU, such that corrective action can be taken (e.g. filter backwash) before the 5 NTU limit of acceptability is exceeded.

Operational monitoring may also be remedial, that is, detecting a problem after it has occurred, such that corrective action may be taken to fix the problem to minimize the extent of unsafe water supply. For example, confirmation that a raw (untreated) water by-pass valve is closed.

1.3 What information should be included in an operational monitoring plan?

The OMP should clearly define the operational monitoring for the specified control measure (that is, the Where?, What?, How?, When? and Who?) alongside the corresponding critical limits and corrective actions to restore effective performance of the control measure.

1.3.1 Operational monitoring parameters

The OMP should clearly describe the following:

- **Where the monitoring will be performed?**

  This refers to the specific location where the operational monitoring will be performed.

  For visual monitoring, this is usually a specific place or asset (for example, a raw water off-take structure, a security fence, a sedimentation tank).

  For measurable operational monitoring (i.e. water quality tests), this is usually a specific water quality sample point (for example, filtered water tank outlet, intermediate distribution tank outlet, consumer standpipe, consumer water meter).

  For clarity and consistency, the exact location for visual inspections or water quality testing sample points should be clearly defined within the OMP. Specifically, the use of unique codes to identify the locations for water quality testing is recommended (for example, using a unique sample point code and corresponding sample point description; see Section 2.1.2 for more information).

- **What monitoring needs to be performed?**

  This means the operational monitoring that needs to be performed to ensure the control measure is working correctly (for example, the integrity of a stock exclusion fence, filtered water turbidity, treated water residual chlorine, intermediate storage tank roof inspection).

- **How the monitoring will be performed?**

  This describes the means by which the operational monitoring will be performed (for example, visual inspection of sedimentation tank, water quality testing of filtered water turbidity).

- **When the monitoring will be performed?**

  This refers to how often the operational monitoring will be performed (e.g. daily, weekly, monthly, and annually).

  The frequency at which an operational monitoring is performed should be sufficient to manage the risk posed by the particular hazard; in general, water quality parameters that may impact public health should be monitored more frequently. For example, treated water chlorine should be monitored frequently (e.g. three times a day), whereas an aesthetic[5] water quality parameter such as colour may be monitored less frequently (e.g. weekly). In certain situations, defining the frequency of monitoring must also take into account practical considerations, for example, the accessibility of the location and seasonal impacts (see examples given in Section 2.2.2 for more information).

  In addition to routine operational monitoring, additional monitoring should be performed following any potential events that may compromise water quality, for example, following a water quality incident at the water treatment plant (such as filter failure or loss of disinfection) or following severe weather events (such as storms, flooding or other natural disasters).

- **Who will perform the monitoring?**

  This refers to the person responsible for performing the operational monitoring (for example, catchment officer, water treatment plant operator/caretaker/technician or public health representative). It is important to clearly define which individual is responsible for performing the monitoring and to make sure that they understand the importance of the task and the potential consequences if the task is not carried out according to the OMP. This individual must be given adequate training and support to be competent to perform the monitoring safely and effectively.

1.3.2 Critical limits

Critical limits are the triggers for when a control measure is no longer considered to be working effectively, and a potential water quality risk exists. Once a critical limit has been breached, an urgent response is usually required to resolve the issue quickly and prevent unsafe drinking-water from reaching consumers. For example, a critical limit for treated water turbidity in the distribution system may be 5 NTU, above which, immediate corrective action is required to restore the operation of the control measure within acceptable limits (that is, to below 5 NTU).

Critical limits will be unique for each specific situation, depending on the prevailing water quality challenges, and may consider the following:

- raw water quality (for example, the impacts of water quantity, as well as climatic events);

5 Aesthetic (in reference to drinking-water quality) relates to the taste, odour or appearance of water.

- the type and effectiveness of water treatment processes (for example, the presence and performance of coagulation/flocculation, clarification, filtration or disinfection);
- intermediate storage and distribution network integrity (for example, structural integrity of assets);
- supply characteristics (such as constant or intermittent supply to consumers); and
- household-level practices (such as household-level water treatment, storage and handling).

Critical limits may be set based on a combination of water quality objectives, historic water quality information and/or operational experience. This may be relevant for operational monitoring of raw water quality (e.g. turbidity), where critical limits may need to be established based on seasonal water quality trends.

Where historic water quality monitoring data is not available (for example, in the case of a new OMP), newly established critical limits must be reviewed regularly and revised as necessary, until water quality trends are established and the critical limits are deemed appropriate for the specific water supply system (see Section 2.2.4).

1.3.3 Corrective actions

The OMP should clearly describe what action is required to restore the operation of the control measure within acceptable limits. Corrective actions will be unique for each specific situation. They should be easy to understand and appropriate for the local situation (for example, they should be achievable within the resource constraints of the particular water supply system).

Corrective actions should be predetermined (that is, clearly documented in a standard operating procedure [SOP]) and the individual responsible for performing that corrective action will be trained and deemed competent to perform the action in question. This will allow the corrective action to be performed quickly and effectively to minimize the risk of unsafe water supply.

In cases where a significant public health risk may exist as a result of the failure of the control measure, corrective actions may require the notification of external public health authorities and the issuing of a public boil water notice.

The corrective action section of an OMP may also include more specific information such as:

- How to perform the corrective action? – With reference to a specific operational procedure to perform a corrective action (e.g. reference to the operational procedure for performing a filter backwash);
- When the corrective action should be performed? – Depends on how urgently the corrective action needs to be performed (for example, higher public health risks should be performed immediately once a critical limit breach has been detected; whereas lower risks may only need to be performed within a day/week of the critical limit breach);
- Who should perform the corrective action? – The person responsible for completing the corrective action; and
- Notification(s) required? – The person(s) who should be notified in the event of the critical limit breach (for example, supervisor, or external parties such as public health representatives or regulators).

Table 3 highlights some of the information that may be included in an OMP. It should be noted however, that the approach to developing an OMP is fully flexible, and the information captured within an OMP should be adapted to suit the specific water supply system and the available resources.

Table 3. *Example of information that may be included in an OMP*

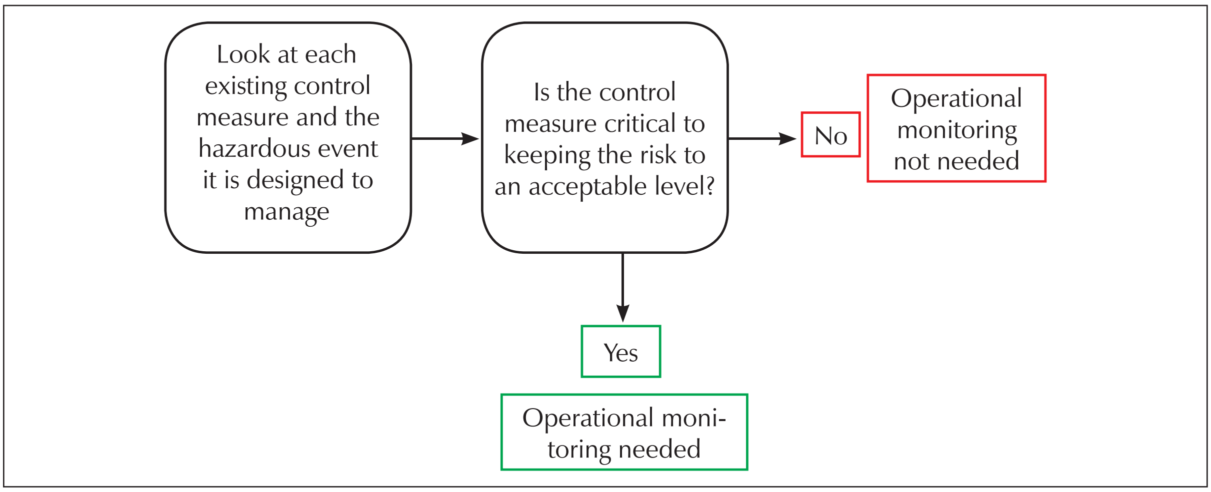
<table>
<tr><th>Control measure</th><th colspan="6">Rapid sand filtration</th></tr>
<tr><td rowspan="2">Operational monitoring</td><td>Where?</td><td>What?</td><td colspan="2">How?</td><td>When?</td><td>Who?</td></tr>
<tr><td>Sand filter (dedicated sample tap)</td><td>Filtered water turbidity</td><td colspan="2">Turbidity tube</td><td>Daily</td><td>Water treatment plant technician</td></tr>
<tr><td>Critical limit</td><td colspan="6">>5 NTU</td></tr>
<tr><td rowspan="3">Corrective action</td><td colspan="6">Initiate filter backwash procedure</td></tr>
<tr><td>How?</td><td colspan="2">When?</td><td colspan="2">Who?</td><td>Notification required?</td></tr>
<tr><td>Refer to SOP How to Perform a Filter Backwash</td><td colspan="2">Immediately following detection of exceeding critical limit</td><td colspan="2">Water treatment plant technician</td><td>Notify supervisor</td></tr>
</table>

1.3.4 Which control measures should be included in an operational monitoring plan

The OMP may not necessarily need to include all of the control measures that have been identified and assessed during WSP development (i.e. Module 4, Figure 1). Rather, the OMP should include all control measures that keep the corresponding risk at a level that is considered to be acceptable.

Figure 2 presents a simple decision tree to help identify which control measures should be included in an OMP.

Figure 2. *Basic decision tree to identify which control measures require operational monitoring*



Part 2. Operational Monitoring Plan Development

Provides stepwise guidance for developing a simple and effective operational monitoring plan

2.1 Getting started

Developing an OMP should be led by the WSP Team[1]. For OMP development, input is required from individuals with experience in the following areas:

- water supply system operations – including catchment, abstraction (that is, raw water harvesting), treatment and network operations;
- water quality monitoring and analysis; and
- water quality risk management.

If the WSP Team does not already include this expertise, assistance should be sought in the relevant areas.

For the development of new OMPs, external input and expertise may also be sought from:

- public health representatives;
- drinking-water quality regulatory bodies;
- local government; and
- non-governmental organizations.

2.1.1 Water quality testing equipment

For operational monitoring water quality testing (such as turbidity, pH and chlorine), appropriate water quality testing equipment is required, alongside basic training in the operation and maintenance of the equipment. SOPs for operation and maintenance of the specific equipment should also be developed.

A relative comparison of water quality testing equipment commonly used for operational monitoring is presented in Table 4. It is important that the choice of testing equipment is appropriate for the specific setting and reflects the local resource availability and supply chains. Key considerations include:

- the cost of the equipment (capital cost);
- the cost of on-going equipment operation and maintenance (that is, operational costs, such as chemical reagents for testing, replacement parts and servicing);
- the accuracy of the equipment;
- the resolution of the equipment (for example, a turbidity meter may read in 0.1 NTU increments [higher resolution] whereas turbidity tubes may only read in 5 NTU increments [lower resolution]);
- the equipment's limit of detection (that is, the lowest/highest result that the equipment can measure);
- ease of operation and training requirements for staff;
- durability under field conditions (resistance to dust, moisture, shock);
- power requirements (for example, battery operated or mains powered);
- local supply chain for chemical reagents, replacement parts, servicing; and
- availability of technical support for resolving technical issues.

Table 4. *Relative comparison of water quality testing equipment commonly used for operational monitoring*

Parameter	Example test equipment	Cost	Accuracy	Resolution	Advantages	Disadvantages
Turbidity	Turbidity tubes	L	L	L	• Low cost, easy to use • Broad measurement range (5 to 2 000 NTU) • Durable for field use • No calibration/servicing/ supply chain required	• Low resolution; may only read in 5 to 10 NTU increments • Cannot measure <5 NTU • Visual measurement; open to user interpretation
	Turbidity meter	H	H	H	• High resolution (0.1 to 0.01 NTU increments • Broad measurement range (0.01 to 1 000 NTU) • Easy to use, rapid result	• Less durable for field use • Requires replacement parts (bulb; glass vials) • Calibration/servicing/supply chain required
Chlorine	Chlorine test strips	M	L	L	• Easy to use; disposable • No calibration/servicing required	• Poor resolution (e.g., may only measure in 0.5 mg/L increments) • Visual measurement (colour change); open to user interpretation • Supply chain for consumable strips required
	Chlorine comparator test kit	M	M	M	• Easy to use • Durable for field use • No calibration/servicing required	• Visual measurement (colour change); open to user interpretation • Requires reagents (DPD powder); supply chain
	Chlorine meter	H	H	H	• Broad measurement range (0.05 to 10 mg/L) • Easy to use	• Less durable for field use • Calibration/servicing/supply chain required (reagents, replacement parts)
pH	pH test strips	M	L	M	• Easy to use; disposable • No calibration/servicing required	• Visual measurement; open to user interpretation • Supply chain for consumable strips required
	pH comparator test kit	M	M	M	• Easy to use • Durable for field use • No calibration/servicing required	• Visual measurement (colour change); open to user interpretation • Requires reagents; supply chain
	pH meter	H	H	H	• High resolution • Easy to use	• Less durable for field use • Calibration/servicing required • Requires supply chain for reagents (calibration buffers) and replacement parts (pH electrode)

L-Low; M-Medium; H-High

2.1.2 Water quality testing sample point identification

For consistency of operational monitoring results, and to provide clarity for field staff performing the operational monitoring, it is beneficial to clearly identify the exact locations in the water supply system where water quality testing samples should be taken. Textbox A provides one example of a basic system for sample point identification that may be adopted to assist OMP development.

(A) Example of a sample point identification system

A sample point identification system should consist of:

(1) a unique sample point code, alongside

(2) a brief but accurate sample point description.

(i) Sample Point Code

The sample point code should be simple and logical. One approach is to use the following identifier:

SP – Location – Number

Where:

SP – Refers to Sample Point

Location – Refers to the area of the water supply system where the sample is being taken, for example: **S** refers to Source
WTP refers to Water Treatment Plant
IS refers to Intermediate Storage
D refers to Distribution system
HH refers to Household

Number – Refers to the next number in sequence (for example, 01, 02, 03…etc.)

For example, the first sample point at the water treatment plant may be referred to as *SP-WTP-01*.

(ii) Sample Point Description:

Each sample point code should have a corresponding sample point description. This description should be brief, but not easily confused with another sample point location. For example, describing a sample point merely as filter water is ambiguous, as it may refer to either the filter water inlet or the filter water outlet. Instead, using the description filter water inlet is clearer and less likely to cause confusion in the field. An example of the application of the sample point identification system is provided in Table 5.

Table 5. *Example application of the sample point identification system.*

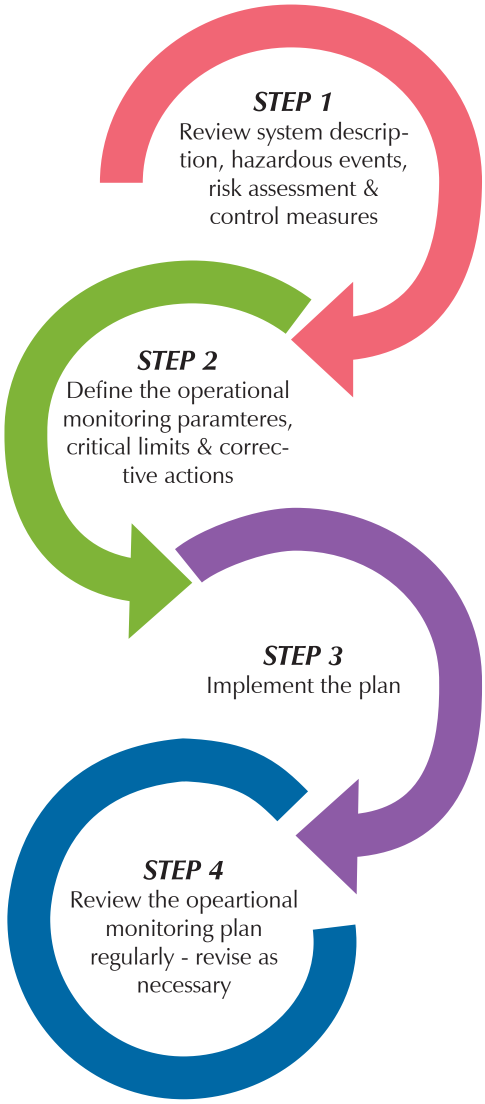
Location	Sample point code	Sample point description
Source	SP-S-01	Raw water off-take outlet
Water treatment plant	SP-WTP-01	Sedimentation tank outlet
	SP-WTP-02	Filter outlet
	SP-WTP-03	Treated water tank outlet
Intermediate storage	SP-IS-01	Intermediate storage outlet
Distribution system	SP-D-01	No. 77, Main Street (water meter)

Note - Visual operational monitoring locations are typically not assigned a sample point code/description, as they often cover a less-specific area, for example, a stock exclusion fence or a filtration tank.

2.2 Developing the operational monitoring plan

Although water supply systems may differ greatly in size, complexity and resources, there are many generalisations which can be made, allowing general guidance for OMP development to be provided. In the following section, step-by-step guidance on developing an OMP is presented (Figure 3). In this section, an OMP is developed from first principles using an example water supply system that is considered to be representative of a typical small- to medium-sized water supply system in lower resource settings (Textbox B). It must be noted, however, that this is just an example water supply system, used to provide general guidance on the steps involved in OMP development. An OMP should be unique for each situation, considering the water quality risks and control measures that are specific to each individual water supply system. It is intended that this example water supply system is used only as a guide, to assist with the development of a system-specific OMP.

Figure 3. *Steps involved in operational monitoring plan development*



2.2.1 Step 1: Review the system description, hazardous events, risk assessments and control measures

Developing an OMP requires that WSP Modules 2, 3 and 4 have already been completed (Figure 1). Before starting to develop an OMP, careful review of the water supply system description Module 2, the identified hazards/hazardous events, control measures and risk assessments (Modules 3 and 4) should take place to ensure that accurate and up-to-date information is used to inform the development of the OMP.

Review the system description

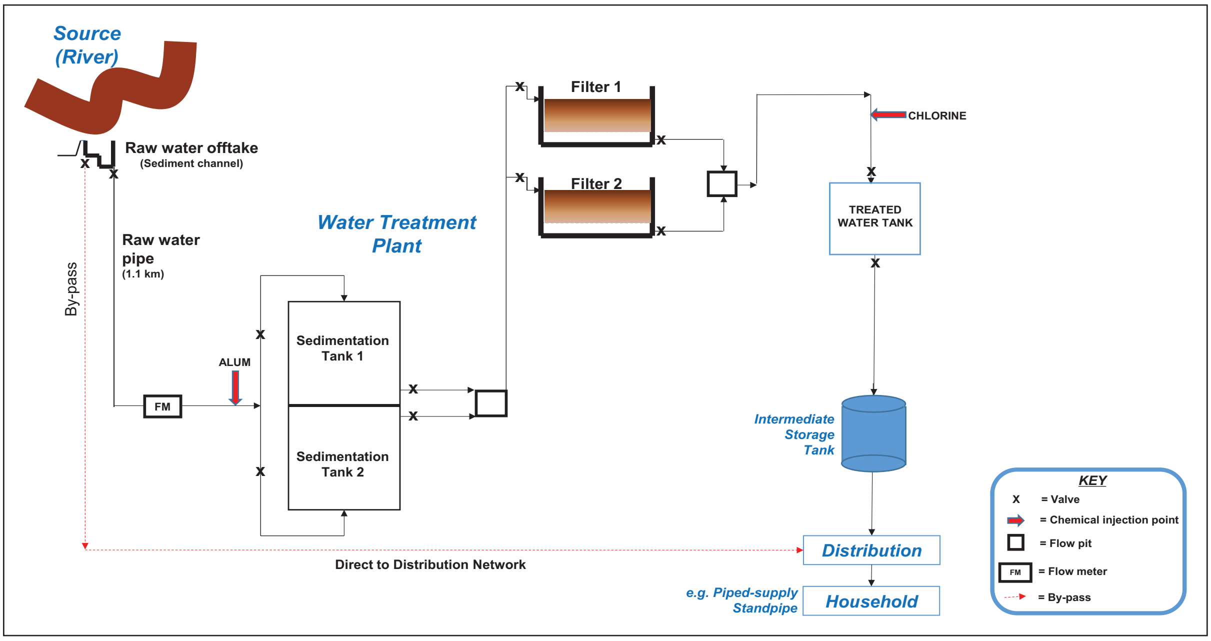
An accurate and up-to-date water supply system description is crucial for OMP development, as it supports the identification of the most appropriate locations for performing the operational monitoring. In particular, an accurate map of the distribution system is required, ideally including the location of intermediate storages (e.g. tanks, reservoirs), points of consumer delivery (such as water meters, public taps and consumer standpipes). A clear understanding of consumer household water treatment and storage practices is also necessary.

A system description for the example water supply system is presented in Textbox B.

(B) Characteristics and process flow diagram for the example water supply system

Water supply system characteristics	
Population served:	1 500 people
Source water:	Surface water (river)
Climate characteristics:	Dry season/wet season
System description:	Source: • Raw water off-take structure (sediment channel) Water Treatment Plant (1 100 m^3/day): • Sedimentation (2 x tanks operating in parallel); aided by chemical coagulant (aluminium sulphate [alum]) • Rapid sand filtration (2 x filter units operating in parallel) • Disinfection (chlorination) • Treated water storage (on-site at water treatment facility) Distribution: • Intermediate storage tank (located in distribution system) • Points of delivery: household piped water supply and customer standpipes Household: • Household water treatment and storage
Key water quality challenges:	• Seasonal source water quality (high turbidity during wet season) • Presence of stock in the catchment upstream of the raw water off-take • Intermittent supply (limited water treatment plant capacity) • Unaccounted water (leakages; illegal connections) • Inappropriate household water treatment, storage and handling practices

Figure 4. *Process flow diagram for the example water supply system*



Review the hazardous events, risk assessments and identified control measures

As discussed in Section 1.1, operational monitoring is specific to the individual control measures identified within a water supply system. As part of WSP development, hazards/hazardous events should be identified and the risks assessed (Module 3), and then reassessed in consideration of the validated control measures (Module 4; Figure 1). The performance of these control measures may then be assessed through operational monitoring. The control measures identified as part of Module 4 of WSP development should be reviewed in advance of developing the OMP to ensure they are complete and up-to-date. Which control measures should be subject to operational monitoring may then be decided, using the basic decision tree shown in Figure 2 (Section 1.3.4).

Tables 6 to 10 describe the hazardous events and corresponding control measures identified for the example water supply presented in Textbox B.

Note – the control measures identified in the following tables are examples only and are not deemed to be exhaustive.

Table 6. *Hazardous events and corresponding control measures identified for the source of the example water supply system*

Process step	Hazardous event (source of hazard)	Hazard classification	Control measure(s)
Source	Rainfall event increasing raw water turbidity from increased run-off	Microbial Physical	Selective raw water harvesting[8]
	Carry-over of sediment/debris from raw water to the water treatment plant	Physical	Raw water off-take sediment channel
	Raw water by-pass emergency valve open allowing untreated water to enter the distribution system	Microbial Physical	Raw water by-pass valve locked in closed position
	Stock defecating in the river upstream of raw water off-take	Microbial Physical	Stock exclusion fencing

Table 7. *Hazardous events and corresponding control measures identified for the example water supply system at the water treatment plant*

Process step	Hazardous event (source of hazard)	Hazard classification	Control measure(s)
Water treatment plant	High turbidity in raw water entering the treatment plant following increased run-off from heavy rains	Microbial Physical	• Selective raw water harvesting[8] • Optimized coagulant dosing[9] • Optimized sedimentation tank operation[9]
	Sub-optimal coagulant dosing (i.e. over-/under-dosing)	Microbial Physical Chemical	• Optimized coagulant dosing[9]
	Carry-over of sediment from sedimentation tanks due to process unit failure	Microbial Physical	• Optimized sedimentation[9] • Tank inspection • Tank cleaning programme
	Breakthrough of turbidity in filtered water following sub-optimal filter performance (e.g. due to inadequate backwash frequency/duration)	Microbial Physical	• Optimized filter operation[9] • Filter inspection • Filter cleaning programme
	Inadequate disinfection as a result of chlorine under-dosing	Microbial	• Optimized chlorination[9]
	Chemical contamination of water supply due to chlorine over-dosing	Chemical	
	Failure of chemical dosing due to chemical run-out event	Microbial Physical Chemical	• Routine chemical level checks (e.g. chlorine, alum)
	Loss of chemical efficacy due to degradation following improper storage and handling	Microbial Physical Chemical	• Chemical stock management procedures

8 Selective raw water harvesting requires sufficient storage capacity to enable the temporary suspension of raw water harvesting or the use of an alternative raw water source.

9 Following validated procedures.

Process step	Hazardous event (source of hazard)	Hazard classification	Control measure(s)
Water treatment plant	Loss of chemical dosing due to pump failure	Microbial Physical Chemical	• Back-up (standby) pump
	Loss of chemical dosing due to power outage	Microbial Physical Chemical	• Fuel powered generator on-site
	Loss of treatment capacity due to asset vandalism/sabotage	Microbial Physical	• Security fencing and gate locks
	Entry of contamination due to tank integrity issues (e.g. animal entry to tank, leaking roof, open hatch)	Microbial Physical	• Tank integrity inspection programme
	Accumulation of sediment in tanks over time	Microbial Physical	• Tank inspection and cleaning programme
	Growth of microbial biofilm on internal surfaces within in-site storage tanks	Microbial	• Maintenance of adequate residual chlorine levels

Table 8. *Hazardous events and corresponding control measures identified for the intermediate storage tank of the example water supply system*

Process step	Hazardous event (source of hazard)	Hazard classification	Control measure(s)
Intermediate storage tank	Entry of contamination due to tank integrity issues (e.g. animal entry to tank, leaking roof, open hatch)	Microbial Physical	• Tank integrity inspection programme
	Accumulation of sediment in tanks over time	Microbial Physical	• Tank inspection and cleaning programme
	Growth of microbial biofilm on internal tank surfaces	Microbial	• Maintenance of adequate residual chlorine levels
	Contamination due to asset vandalism/sabotage	Microbial Physical Chemical	• Security fencing and gate locks

Table 9. *Hazardous events and corresponding control measures identified for the distribution system of the example water supply system101112*

Process step	Hazardous event (source of hazard)	Hazard classification	Control measure(s)
Distribution	Entry of contamination due to asset integrity issues (e.g. broken mains, leaking pipes/valves/fittings)	Microbial Physical	• Asset maintenance programme
	Re-suspension of deposited sediment following abnormal flow conditions	Microbial Physical	• Routine mains cleaning programme
	Sub-optimal chlorine concentration in the distribution system	Microbial Chemical	• Optimized chlorination[9]
	Growth of microbial biofilm on internal pipework	Microbial	• Maintenance of sufficient residual chlorine concentration • Mains cleaning programme
	Entry of contamination due to backflow[10]	Microbial Physical Chemical	• Fitting of backflow prevention devices on high risk connections
	Entry of contamination due to illegal[11] and/or cross connections[12]	Microbial Physical Chemical	• Routine plumbing inspection programme
	Entry of contamination due to insanitary conditions around, or damage to, consumer standpipes	Microbial Physical	• Routine standpipe inspection programme
	Entry of contamination due to improper water main installation/ repair	Microbial Physical Chemical	• Procedures for new mains installation and repair

10 Unintentional flow of contaminated water in the reverse direction to normal drinking-water and introducing chlorine reactive substance.

11 Unauthorised connections to the drinking-water supply pipes; illegal connections are often sources of leakages, and may introduce backflow or cross connections due to poor quality work or a lack of understanding of plumbing risks.

12 Connection between drinking-water pipes and non-drinking-water pipes (such as sewerage or recycled water pipes).

Table 10. *Example hazardous events and corresponding control measures identified at the household level*

Process step	Hazardous event (source of hazard)	Hazard classification	Control measure(s)
Household level	Introduction of, or failure to remove, contamination due to inappropriate household water treatment practices (e.g. use of insanitary household water filter)	Microbial Physical Chemical	Education and awareness programme for appropriate household water treatment, storage and handling practices
	Introduction of contamination due to inappropriate storage practices (e.g. use of inappropriate, insanitary storage vessel)	Microbial Physical Chemical	
	Introduction of contamination due to inappropriate handling practices (e.g. use of inappropriate, insanitary dipping utensil)	Microbial Physical	

2.2.2 Step 2: Define the operational monitoring parameters, critical limits and corrective actions

Operational monitoring of the control measures should be defined, alongside their corresponding critical limits and corrective actions (Section 1.3).

Define operational monitoring at the source

The source refers to everything upstream of the point of raw water harvesting (including the catchment area). Operational monitoring of control measures at the source may provide an early indication of water quality issues (such as a temporary spike in raw water turbidity or the presence stock upstream of a raw water off-take), allowing timely corrective action to be implemented before downstream water quality is significantly impacted.

The types of control measures identified at the source will depend on the particular situation, including the type of land-use in the catchment and the available resources. Table 11 provides some examples of control measures at the source, alongside examples of operational monitoring that may be applied to ensure the control measures are performing within acceptable limits.

Note: For more examples of control measures and associated operational monitoring for Sections 2.2.2, please refer to *Water Safety Plan Manual*[1].

Table 11. *Examples of generic control measures alongside corresponding operational monitoring at the source*

Example control measures	Example corresponding operational monitoring
Stock exclusion fencing	Fence integrity inspection (V)
Maintenance of vegetated zones along source water course (e.g. riparian buffer zone)	Buffer strip condition inspection (V)
Engineered drainage diversion ditches	Inspection of drainage ditches (V)
Selective raw water harvesting (e.g. sufficient storage capacity to enable temporary suspension of raw water harvesting or use of an alternative raw water source)	Monitoring of raw water quality (e.g. turbidity; M) ensuring raw water is only harvested when the quality is deemed appropriate
Raw water off-take pre-treatment (e.g. screens, sediment channels, aeration weirs)	Monitoring of water quality before and after treatment unit (M)
Raw water storage	Monitoring of raw water storage water quality (M)
Multi-level raw water off-take	Monitoring of harvested raw water quality (M)
Catchment management controls (e.g. declared water supply zones and land-use restrictions; planning permit system)	Inspections of land-use and planning approvals (V)
Codes of practise for potentially hazardous activities (e.g. slurry/pesticide application, wastewater disposal)	On-site inspections of activities for compliance to codes of practice (V)

V - visual; M – measurable.

Where pre-treatment steps are present at the raw water off-take (such as aeration weir, screen, and sediment channel), visual inspections of these units should be routinely performed as part of operational monitoring. In addition, basic water quality testing should be performed (such as turbidity measurement), both before and after the treatment unit, to determine if the treatment unit is performing within acceptable limits.

Depending on the specific circumstances, the frequency of operational monitoring at the source must take into account practical considerations. For example, if a raw water off-take structure is located at a significant distance from the water treatment facility (for example, high in the catchment, 20 km from the water treatment facility), more frequent inspections (e.g. daily) may not be practical due to resource limitations. In this case, less frequent (e.g. monthly) inspections may be more appropriate. Further, if the road is inaccessible during the wet season, practical and safe operational monitoring may only be possible during the dry season. In this example, other operational monitoring may be possible to manage the risk during the wet season, such as more frequent monitoring of the raw water quality at the entry point to the water treatment plant. In addition, inspecting stock exclusion fences may cover vast areas of farm land far upstream of a raw water off-take, so regular monitoring (for example, weekly) may not be practical. In this case, less frequent monitoring may be more appropriate (for example, annually during calving/lambing season, when water quality risks from harmful microorganisms associated with juvenile stock is greatest) or on an event basis (for example, following reports of stock presence in the source water).

Where appropriate, seasonal critical limits may be set for raw water quality parameters, for example, reflecting the annual deterioration in raw water quality during the wet season (see Table 13). Such decisions should be based on historical water quality data (where available) and operational experience, and should not compromise the effectiveness of downstream water treatment processes.

Textbox C describes the identification of sample points for operational monitoring water quality testing at the source in the example water supply system. Table 13 presents the OMP for the source, based on the control measures identified in Table 6.

(C) Operational monitoring at the source: Example water supply system

For the example water supply system, two sample points have been identified for operational monitoring water quality testing at the source, the details of which are presented in Figure 5 and Table 12.

Figure 5. *Sample point locations for water quality testing at the source*

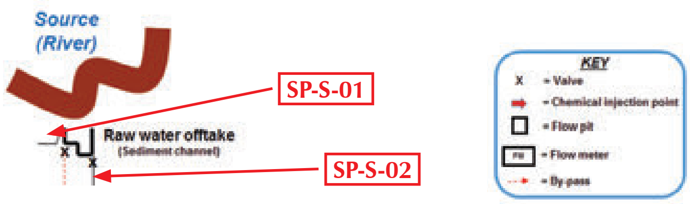


Table 12. *Sample point selection and water quality testing for operational monitoring at the source*

Sample point code	Sample point description	Minimum recommended testing	Purpose for selection
SP-S-01	Raw water (pre-sedimentation channel)	Turbidity	• Baseline data to be used in conjunction with SP-S-02 to determine the performance of the sediment channel • River water quality assessment (e.g. allows departures from normal trends to be detected, which may indicate potential source water quality risks, for example, changes in land-use in the catchment)
SP-S-02	Raw water off-take structure outlet	Turbidity	• Used in conjunction with SP-S-01 to evaluate performance of the sedimentation channel • Provides indication of the raw water quality for downstream treatment processes (i.e. early warning of poor water quality entering the water treatment plant)

Table 13. *OMP at the source for the example water supply system*

Control measure	OPERATIONAL MONITORING					Critical limit	Corrective action Consider situation and decide on the most appropriate response:
	Where?	What?	How?	When?	Who?		
Process step: Source							
Selective raw water harvesting	Raw water off-take structure inlet **(SP-S-01)**	Turbidity monitoring	Turbidity tubes	Daily – wet season Weekly - dry season	Caretaker	> 2 000 NTU wet season > 1 000 NTU dry season	• Cease raw water harvesting until turbidity drops below critical limit
Raw water off-take sediment channel	Raw water off-take structure outlet **(SP-S-02)**	Turbidity monitoring	Turbidity tubes	Daily – wet season Weekly - dry season	Caretaker	> 500 NTU wet season > 100 NTU dry season	• Reduce raw water flow rate • Cease raw water harvesting until turbidity drops below critical limit • Clean sediment channel
	Raw water off-take structure (sediment channel)	Presence of excessive levels of sediment/ debris	Visual inspection of sediment channel	Daily – wet season Weekly - dry season	Caretaker	Excessive levels of sediment/ debris within structure	• Clean sediment channel
Raw water by-pass valve lock	Raw water by-pass valve at raw water off-take structure	Position of raw water by-pass valve and lock integrity	Visual inspection of valve position and lock integrity	Weekly	Caretaker	Valve position open and/or lock open/ damaged	• Close valve • Close lock; replace if damaged If untreated water is expected to have entered distribution, undertake immediate water quality testing to determine impact
Stock exclusion fence	Farm perimeter 3 km upstream of raw water off-take	Integrity of upstream stock exclusion fence	Visual inspection of stock exclusion fence	Annually (or following notification of stock presence in source water)	Catchment officer	Damaged fencing and/or stock present in the river	• Repair fence • Remove stock from river if present

Define operational monitoring at the water treatment plant

Operational monitoring at the water treatment plant should involve:

(1) **visual inspection:** To check treatment units for any obvious visual signs of sub-optimal performance or failure (e.g. breaks, blockages, leaks, overflows, unhygienic/insanitary conditions, carry-over of sediment, effluent quality is visually poor); and

(2) **water quality testing:** To confirm the control measure is operating within acceptable limits.

Table 14 provi des some examples of control measures at the water treatment plant, alongside examples of operational monitoring that may be applied to ensure the control measures are performing within acceptable limits.

Table 14. *Examples of generic control measures at the water treatment plant source alongside corresponding operational monitoring*

Example control measures	Example corresponding operational monitoring
Validated treatment units (e.g. sedimentation, coagulation/flocculation, clarification, filtrations, disinfection)	• Water quality monitoring (e.g. pH, turbidity, chlorine [M])
Plant shut down (manual or automatic)	• Confirmation of plant shut-down on trigger limits (V)
Site/asset security (e.g. fencing, locks on access hatches)	• On-site security inspections (V)
Standard operating procedures for facility operations	• Check compliance with relevant SOP (V)
Chemical quality assurance purchasing policy	• Check compliance with policy (V)
Chemical stock management programme	• Check chemical stock management practices (V)
Operational staff training and competency programme	• Field check staff competency (V)
Back-up pumps (e.g. for chemical dosing, backwashing)	• Routine testing of back-up pump operation (V)
Back-up power supply	• Routine testing of back-up power supply (V)
Asset inspection and maintenance programmes	• Inspect programme implementation (V)

V - visual; M – measurable.

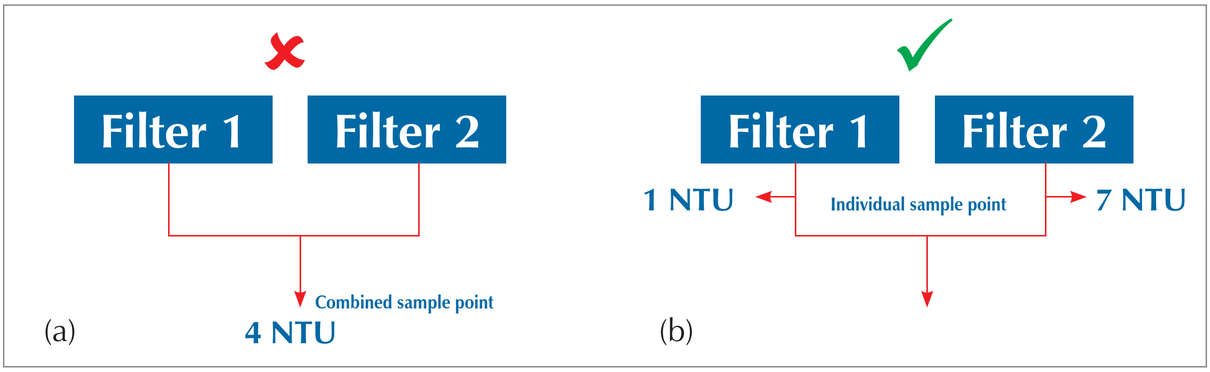
Regular monitoring of the raw water entering the water treatment plant is critical to optimizing the water treatment process and may provide an early indication of the potential for water quality issues downstream (such as sub-optimal coagulation, sedimentation, filtration and chlorination). Depending on the variability of the raw water quality, monitoring of the raw water quality should generally be performed regularly (e.g. once per day at a minimum).

In general, the performance of each individual treatment process (e.g. coagulation/flocculation, sedimentation/clarification, filtration, disinfection) should be assessed through operational monitoring. As described in Section 2.2.2, water quality testing should be performed both before and after each treatment unit, to accurately determine the performance of that particular control measure.

In certain situations, chemical coagulants are added to assist with the removal of particles from the water. If a chemical coagulant is added to the water (such as alum), it is important to understand the optimum conditions required for effective coagulation. The pH of the water during the coagulation process and the coagulant dose are important factors to consider. In general, alum (aluminium sulphate) works effectively between pH 5.5 and 7.5, whereas ferric salts (such as ferric sulphate and ferric chloride) work between pH 5.0 and 8.5. (Note: both coagulants work best between pH 5.5 and 6.5[13] but to balance optimized coagulation alongside other water quality considerations, it is best generally to maintain the pH of the water between pH 6.5 and 8.5[14]). The coagulant dose must also be optimized for the specific raw water quality experienced at the treatment facility (using, for example, turbidity as a general indicator for raw water quality). In general, water with a higher turbidity (i.e. dirtier water) will require a higher dose of coagulant. The optimum coagulant dose may be estimated by performing a jar-test, that is, a laboratory test where different concentrations of coagulant are added to samples of the raw water at different pH values to determine the optimum conditions for coagulation. As the raw water quality may fluctuate regularly (and rapidly), jar testing should be performed at a frequency, that manages the risk for the particular situation. For example, if the raw water quality fluctuates regularly, jar testing should be performed more regularly (for example, daily); if the raw water quality is more stable, then it may be appropriate to perform jar testing less regularly (for example, weekly).

If multiple units of the same treatment process are in place (for example, two filter units operating in parallel or in series), it is recommended to monitor the water quality from each treatment unit individually to accurately determine the individual performance of each treatment unit. If only the combined effluent sample is tested (as opposed to the individual effluent samples from each unit), then the good performance of one unit may hide the poor performance of the other. For example, if two filter units (filter 1 and 2) are operating in parallel, but operational monitoring is only performed on the combined effluent, a turbidity result of 4 NTU may be recorded, which would indicate that both filters are producing effluent below the critical limit, which in this example is <5 NTU (Figure 6). However, if the operational monitoring is performed on the effluent from each individual filter, then it becomes apparent that, in actual fact, filter 1 is producing effluent within specification at 1 NTU (i.e. <5 NTU), but filter 2 is producing effluent at 7 NTU, which is above the critical limit of 5 NTU. In this case, careful operational monitoring has identified that only filter 2 is performing out of specification, which would have otherwise gone unnoticed. Further, it is clear that only filter 2 requires backwashing, not filter 1. As such, effective operational monitoring may not only manage water quality risks, but may also improve operational efficiency and save resources.

Figure 6. *Example illustrating the importance of monitoring the effluent from each individual process unit at a water treatment plant; here, the poor performance of filter 2 is hidden when only the combined effluent is sampled (a); whereas monitoring each filter unit individually clearly indicates that filter 2 is performing poorly and requires corrective action (b).*



13 United States Environmental Protection Agency: drinking-water treatability database. http://iaspub.epa.gov/tdb/pages/treatment/, visited on 8th August, 2015.
14 World Health Organization (2011). Guidelines for Drinking-water Quality. 4th Edn. Geneva, Switzerland.

Critical limits at the water treatment plant will be unique for each specific situation and depend on many factors, including the prevailing water quality challenges and the type of treatment processes in place. In addition, critical limits for a parameter will vary as the water travels through a treatment plant, for example, critical limits for turbidity in earlier process steps (e.g. after sedimentation) would be higher than after process steps near the end of the treatment chain (e.g. filtered water). Textbox D provides guidance on the conditions required for effective chlorine disinfection, which may be used to inform the establishment of critical limits for filtration and chlorine disinfection processes at the water treatment plant and during distribution. In general, critical limits for operational monitoring should be more stringent than the values described in Textbox D, to allow time for corrective action to be taken (that is, set preventatively; see Section 1.3.2). For example, the critical limit for filtered water turbidity may be set to >0.5 NTU, so appropriate corrective action may be taken before the turbidity reaches >1 NTU.[15]

(D) Summary of the conditions required for effective chlorine disinfection

For effective chlorine disinfection of drinking-water, the WHO[14] recommends the following:

Turbidity:	<1 NTU **(preferably lower where achievable)** Where not achievable, <5 NTU should be the aim; above 5 NTU, chlorination should still be practised, but higher chlorine doses or contact times will be required to inactivate harmful microorganisms
pH:	<pH 8.0 Above pH 8.0, chlorination should still be practised but higher chlorine doses or contact times will be required to inactivate harmful microorganisms
Minimum chlorine contact time[15]:	30 minutes contact with a minimum residual chlorine concentration of 0.5 mg/L (where the pH of the water is <pH 8.0).

Once chlorine disinfection at the water treatment plant is complete, the residual chlorine concentration during distribution to the point of consumer delivery (e.g. water meter, standpipe) should be between 0.2 and 0.5 mg/L to balance disinfection considerations with consumer acceptability (i.e. taste, odour of the water).

A minimum residual chlorine concentration of 0.2 mg/L must always be maintained at the point of delivery[14].

- This implies that, to a degree, the water is protected from recontamination by certain microorganisms, and helps to ensure the water is safely delivered to the customer.

In some cases, it may be necessary to maintain a residual chlorine concentration >0.5 mg/L in some parts of the distribution system (for example, early in the distribution system), to ensure a minimum residual chlorine concentration of 0.2 mg/L is achieved throughout the entire system, to the point of customer delivery.

When setting the chlorine dose, adequate disinfection must never be compromised due to consumer acceptability considerations.

At all times, however, the concentration of chlorine in water supplied to customers should be below the guideline value of 5 mg/L[14].

15 Chlorine needs time to kill or inactivate microorganism during the disinfection process. Chlorine contact time is a measure of the minimum amount of time required for contact between chlorine and drinking-water for effective disinfection to occur.

The optimum chlorine dose at the water treatment plant will be different for each individual situation, and may depend on:

- the water quality (and chlorine demand);
- the minimum required chlorine contact time;
- the extent of chlorine decay[16] in the distribution system; and
- the potential for consumer acceptability issues (i.e. chlorine taste/odour).

Sufficient chlorine must be added at the water treatment plant to ensure a minimum chlorine residual concentration of 0.2 mg/L at the point of delivery. As such, the optimum chlorine dose, and the corresponding critical limits, will differ for each water supply system, depending on the characteristics of that system. System specific operational knowledge and experience for the particular water supply system is required to establish appropriate critical limits for operational monitoring of chlorination. Guidance on effective chlorination practices is presented in *Principles and practices of drinking-water chlorination: A guide to strengthening chlorination practices in small- to medium-sized water supplies*[17].

Textbox E describes sample point identification for operational monitoring water quality testing at the water treatment plant in the example water supply system. Table 16 describes the OMP for the water treatment plant, based on the control measures identified in Table 7.

16 Chlorine decay is the term given to the decrease in chlorine concentration observed as water passes through a water supply system due to the reactions between chlorine and organic and inorganic materials.

17 World Health Organization Regional Office for South-East Asia (2017). Principles and practices of drinking-water chlorination: a guide to strengthening chlorination practices in small- to medium-sized water supplies.

(E) Operational monitoring at the water treatment plant: Example water supply system

For the example water supply system, eight water quality testing sample points have been identified for operational monitoring at the water treatment plant, the details of which are presented in Figure 7 and Table 15.

Figure 7. *Sample point locations for water quality testing at the water treatment plant*

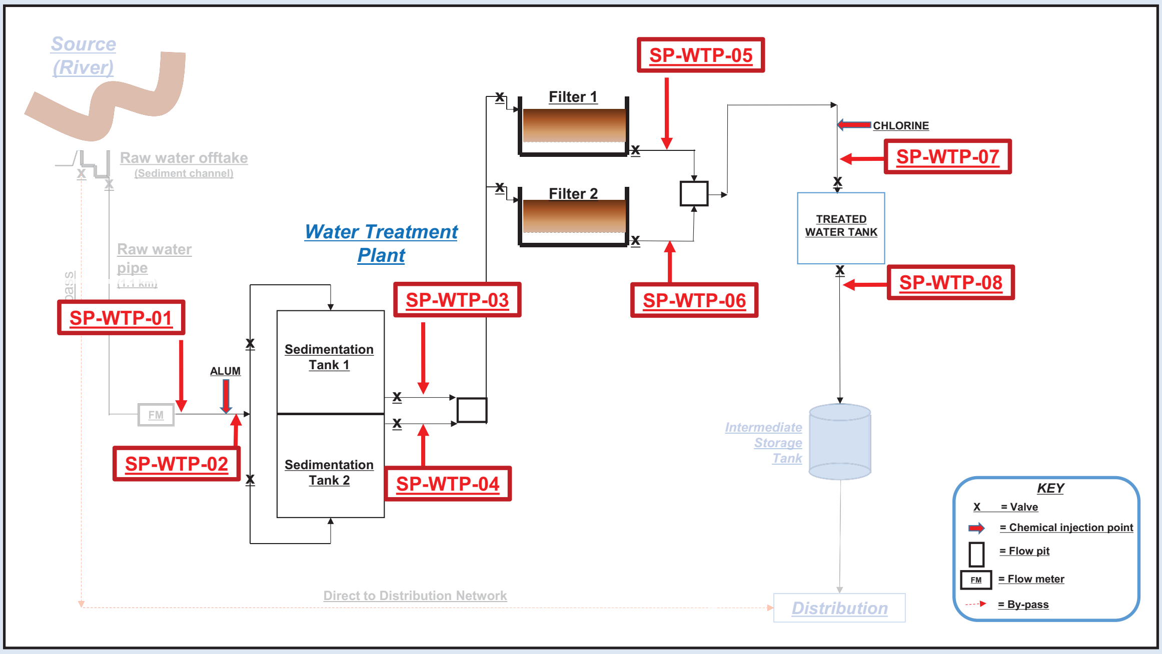


Table 15. *Sample point selection and water quality testing for operational monitoring at the water treatment plant*

Sample point code	Sample point description	Minimum recommended testing	Purpose for selection
SP-WTP-01	Plant inlet (pre-alum dose)	pH Turbidity	• Provides indication of water quality entering the plant (i.e. may trigger plant shut-down) • May provide early warning for potential for treatment issues downstream (e.g. coagulation failure, filter overloading, sub-optimal chlorination) • Optimum sample point for jar testing sample to optimize coagulant (alum) dosing (i.e. to determine optimum alum dose and pH for coagulation) • May indicate raw water pipe integrity issue (e.g. burst, leak)

(E) Operational monitoring at the water treatment plant: Example water supply system….Continued

Sample point code	Sample point description	Minimum recommended testing	Purpose for selection
SP-WTP-02	Sedimentation tank inlet (post-alum dose)	pH	• Allows monitoring and optimization of dosed water pH to ensure pH is optimum for coagulation (i.e. may trigger adjustment of raw water pH or alum dose)
SP-WTP-03	Sedimentation tank 1 outlet	Turbidity	• Allows monitoring of each individual sedimentation tank to ensure sedimentation process is optimized (i.e. may trigger optimization of coagulation, tank cleaning or reduction in plant flow rate) • May provide early warning for potential downstream impacts (e.g. filter overloading, sub-optimal chlorination)
SP-WTP-04	Sedimentation tank 2 outlet	Turbidity	
SP-WTP-05	Filter 1 outlet	Turbidity	• Allows monitoring of each individual filter unit to ensure filtration process is optimized (i.e. may trigger optimization of upstream processes and/or filter backwashing) • May provide early warning for potential treatment issues downstream (e.g. sub-optimal chlorination)
SP-WTP-06	Filter 2 outlet	Turbidity	
SP-WTP-07	Treated water tank inlet (post-chlorine dose)	Chlorine pH	• Allows monitoring and optimization of chlorination for effective disinfection (i.e. may trigger adjustment to pH or chlorine dose)
SP-WTP-08	Treated water tank outlet (entry point)	Chlorine pH Turbidity	• Allows monitoring and optimization of chlorination for effective disinfection (i.e. may trigger adjustment to pH, chlorine dose and/or plant flow rate) • Allows verification of the final water quality prior to supply to customers (i.e. may trigger optimization of upstream treatment processes) • May indicate the presence of tank integrity issue (e.g. leaking roof, damaged fittings) • May indicate that tank cleaning is required

Table 16. *OMP for the water treatment facility for the example water supply system*

Process step	Control measure	OPERATIONAL MONITORING					Critical limit	Corrective action Consider situation and decide on the most appropriate response:
		Where?	What?	How?	When?	Who?		
Treatment	**Optimized coagulant dosing**	Plant inlet (pre-alum dose; SP-WTP-01)	Raw water turbidity measurement	Turbidity tubes	Daily	Technician	> 500 NTU wet season > 100 NTU dry season	Close raw water offtake valve and cease extraction until turbidity drops below critical limit
		Plant inlet (pre-alum dose; SP-WTP-01) & Sedimentation tank inlet (post-alum dose; SP-WTP-02)	Raw water pH measurement	pH	Daily	Technician	pH < 6.5 pH > 8.0	Adjust raw water pH to between pH 6.5 and 8.0
		Coagulant dose pump	Alum dose pump calibration	Dose pump calibration test	Daily	Technician	Pump dose rate more than ± 10 % of set-point	Recalibrate dose pump as per operational procedure
		Plant inlet (pre-dose; SP-WTP-01)	Raw water jar test	As per jar test procedure	Daily	Technician	Jar test result more than ± 10 % of current alum dose	Adjust coagulant (alum) dose
	Optimized sedimentation	Sedimentation tank 1 and 2 outlet (SP-WTP-03 & SP-WTP-04)	Post-sedimentation turbidity	Turbidity tube	Daily	Technician	> 50 NTU	Reduce flow-rate through the plant Optimize coagulant dosing Programme cleaning of affected tank(s)
	Sedimentation tank inspection and cleaning programme	Sedimentation tanks 1 & 2	Signs of sediment accumulation in tanks/ sediment carry-over	Visual inspection of sedimentation tanks 1 & 2	Daily	Caretaker	Excessive levels of sediment accumulation or carry-over	Programme cleaning of affected tank(s)

Process step	Control measure	OPERATIONAL MONITORING					Critical limit	Corrective action Consider situation and decide on the most appropriate response:
		Where?	What?	How?	When?	Who?		
Treatment… continued	**Optimized filtration**	Filter 1 & 2 outlet (SP-WTP-05 & SP-WTP-06)	Filtered water turbidity	Turbidity tubes	Twice daily	Technician	> 5 NTU	Backwash affected filter(s)
	Filter inspection	Filters 1 & 2	Indication of filter overloading	Visual inspection of filters 1 & 2	Daily	Caretaker	Indication of filter overloading (e.g. breakthrough, clogging, reduced filter flow-rate)	Backwash affected filter(s) Consider need to replace filter media
	Optimized chlorination	Treated water tank inlet (SP-WTP-07) & outlet (SP-WTP-08)	Chlorine residual	Residual chlorine analyser	Three times per day	Technician	< 0.5 mg/L > 2 mg/L	Confirm correct chlorine dose is being applied; optimize as required Confirm chlorine pump functioning correctly (e.g. blockage, leakage) If chlorine level is low, check chlorine tank level and for any leaks on the chlorine dosing line Confirm chlorine batch prepared correctly according to SOP If undisinfected water is thought to have entered distribution, undertake immediate water quality testing to determine impact and appropriate action
		Treated water tank inlet (SP-WTP-07) & outlet (SP-WTP-08)	pH	pH meter	Daily	Technician	< pH 6.5 > pH 8.5	Confirm correct coagulant and chlorine dose is being applied; optimize as required Adjust pH to within acceptable range
		Treated water tank outlet (SP-WTP-08)	Turbidity	Turbidity tubes	Three times per day	Technician	> 5 NTU	Review upstream water quality trends (coagulation, filtration) Clean treated water tank

Process step	Control measure	OPERATIONAL MONITORING					Critical limit	Corrective action
		Where?	What?	How?	When?	Who?		Consider situation and decide on the most appropriate response:
Treatment… continued		Chlorine dose pump	Chlorine dose pump calibration	Dose pump calibration test	Daily	Technician	Pump dose rate more than ± 10 % of set-point	Recalibrate dose pump as per operational procedure
	Chemical level inspection	Alum tank Chlorine tank	Chemical level in storage tanks	Visual inspection of tank levels	Daily	Caretaker	Chemical levels < 30 % of tank capacity	Replenish chemical
	Stock management procedures	Chemical storage shed	Chemical stock management procedures being applied	Visual inspection of expiry date and storage conditions for chemical stock	Monthly	Caretaker	Stock expired or stored inappropriate (e.g. bags damaged, unsealed, wet)	Replace affected stock
	Back-up chemical dose pumps	Chemical dosing room	Back-up dose pumps operation	Test pump operation	Monthly	Caretaker	Pump not operational	Fix or replace pump as required
	Fuel generator	Generator room	Fuel generator operation and fuel levels	Test generator operation and fuel level	Monthly	Caretaker	Generator not operational or low on fuel (< 30 %)	Fix generator Refill fuel tank
	Security fencing and gate locks	Water treatment plant compound	Integrity of security fencing and lock	Visual inspection of perimeter fence and gate lock	Weekly	Caretaker	Damaged fencing or lock	Repair affected assets

Define operational monitoring at intermediate storages

Well maintained intermediate storages help preserve water quality after treatment by minimizing the risk of recontamination during storage. Fully enclosed intermediate storage tanks (or reservoirs) may act as a physical barrier to prevent environmental contamination from coming in contact with drinking-water (for example, dust, animal excrement). Enclosed storages may also help to maintain an adequate residual chlorine concentration, by minimizing the potential for chlorine to escape from the water into the air (in a process called volatilization). However, poorly maintained intermediate storages are often a cause of water quality incidents and their regular monitoring and inspection is a key requirement for operational monitoring.

Effective operational monitoring of intermediate storage integrity should involve:

(3) **visual inspections**: to check a tank for leaking or damaged roof, open or unlocked access hatches, evidence of animal activity (e.g. excrement, diggings, dead animals), overhanging branches above a tank (where animals may roost), integrity issues with security fencing/ locks; and

(4) **water quality testing:** to monitor for water quality changes during storage, which may indicate tank integrity issues, such as elevated turbidity levels, low residual chlorine concentration or sub-optimal pH (all of which may compromise the effectiveness of chlorine disinfection and increase the risks of microbial recontamination).

In addition to routine operational monitoring at intermediate storages, it is important that additional monitoring is performed following any severe weather events or natural disasters that may compromise the storage integrity (for example, severe winds, and earthquake).

Table 17 provides examples of common control measures for intermediate storage tanks, alongside options for their operational monitoring.

Table 17. *Examples of generic control measures for intermediate storages alongside corresponding operational monitoring*

Example control measures	Example of corresponding operational monitoring
Optimizing storage detention times to minimize water age	Residual chlorine concentration; pH (M)
Animal proofing	Site inspection for evidence of animal activity/animal access (V)
Tank maintenance programme	Asset integrity inspections (V)
Tank cleaning programme	Turbidity, residual chlorine concentration (M) Physical inspection (V)
Use of materials suitable for contact with drinking-water (e.g. fittings, valves, pipe material, tank liners)	Check purchasing policy compliance (V) Check certificates of compliance to the appropriate manufacture standards (V)
Site/asset security (e.g. fencing, locks on access hatches)	On-site security inspections (V)
Standard operating procedures for operation of intermediate storages	Check compliance with relevant SOP (V)
Maintenance of adequate residual chlorine concentration (if storage covered)	Residual chlorine concentration (M)

V – visual; M – measurable.

Textbox F describes water quality testing sample point identification for operational monitoring at the intermediate storage tank in the example water supply system. Table 19 describes the OMP for the water treatment plant, based on the control measures identified in Table 8.

(F) Operational monitoring at the intermediate storage tank: Example water supply system

For the example water supply system, one water quality testing sample point has been identified for operational monitoring at the intermediate storage tank, the details of which are presented in Figure 8 and Table 18.

Figure 8. *Sample point location for water quality testing at the intermediate storage tank*

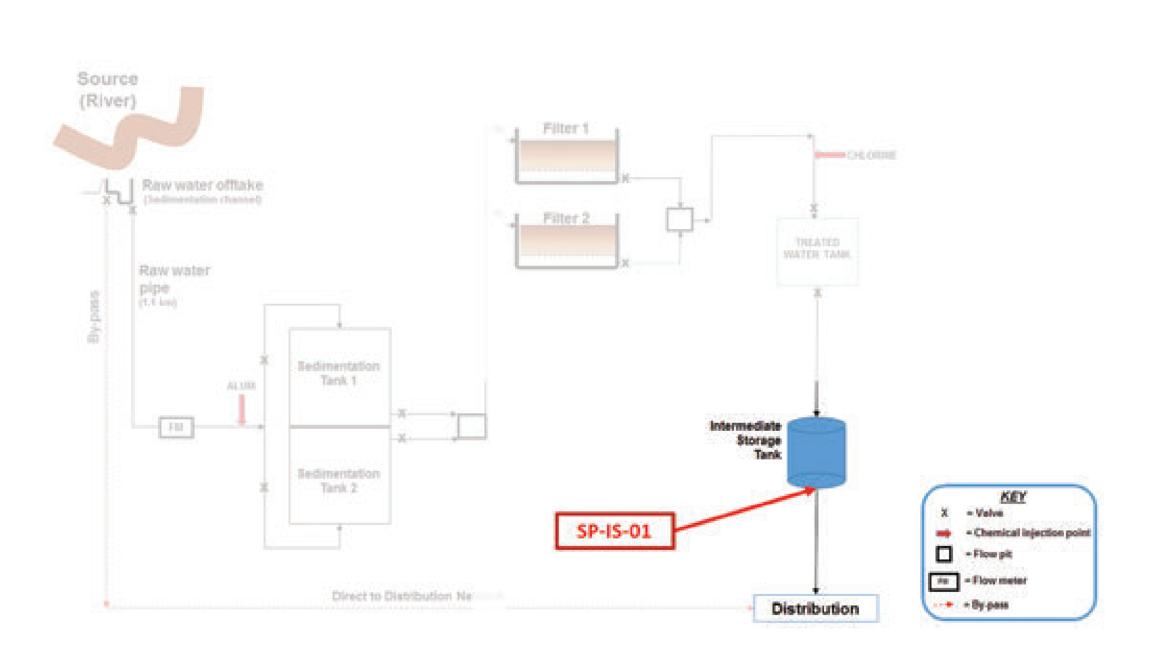


Table 18. *Sample point selection and water quality testing for operational monitoring at the intermediate storage tank*

Sample point code	Sample point description	Minimum recommended testing	Purpose for selection
SP-IS-01	Tank outlet	Chlorine pH Turbidity	• May provide indication of water quality deterioration during intermediate storage • May indicate tank integrity issue (triggering tank inspection and/or cleaning) • May provide early warning for potential downstream customer impacts

Table 19. *OMP for the intermediate storage tank for the example water supply system*

Control measure	OPERATIONAL MONITORING					Critical limit	Corrective action Consider situation and decide on the most appropriate response:
	Where?	What?	How?	When?	Who?		
Process step: Intermediate storage tank							
Tank integrity inspection	Intermediate storage tank	Tank integrity check for possible points of contamination entry (e.g. roof, hatches, fittings, air vents, bird/insect proofing, overhanging vegetation)	Visual inspection of tank components	Monthly	Network operator	Evidence of tank integrity breach	• Repair affected components
Tank cleaning programme	Tank outlet (SP-IS-01)	Turbidity of tank effluent	Turbidity tubes	Once per week	Technician	> 5 NTU	• Investigate upstream water quality tends to determine source of elevated turbidity: Clean tank if it is the suspected source
Maintenance of sufficient residual chlorine concentration	Tank outlet (SP-IS-01)	Residual chlorine concentration in tank effluent	Residual chlorine analyser	Once per week	Technician	< 0.2 mg/L > 1.0 mg/L	• Review chlorination at water treatment facility; optimize as necessary • If low chlorine levels detected: – assess the need to clean tank if turbidity also elevated – inspect tank integrity – assess if tank detention times are optimized to minimize water age If disinfection is thought to be compromised, undertake immediate water quality testing to determine impact and appropriate action

Control measure	OPERATIONAL MONITORING					Critical limit	Corrective action Consider situation and decide on the most appropriate response:
	Where?	What?	How?	When?	Who?		
Maintenance of sufficient residual chlorine concentration... continued	Tank outlet (SP-IS-01)	pH of tank effluent	pH meter	Once per week	Technician	< 6.5 mg/L > 8.5 mg/L	• Investigate source of pH change • Adjust pH If disinfection is thought to be compromised, undertake immediate water quality testing to determine impact and appropriate action
Security fencing and gate locks	Intermediate storage tank compound	Integrity of security fencing and lock	Visual inspection of perimeter fence and gate lock	Weekly	Network operator	Damaged fencing or lock	• Repair fencing and/or lock as required

Define operational monitoring within the distribution system

Operational monitoring within the distribution network is important to ensure that water quality is maintained through to the point of delivery to the consumer. Operational monitoring within the distribution network should involve:

(5) **visual checks:** for distribution network integrity issues such as valve/fittings/mains leaks, plumbing issues (e.g. backflow, cross connections or illegal connections) and insanitary or unhygienic conditions at points of consumer delivery (e.g. standpipes); and

(6) **water quality testing:** to monitor for potential water quality changes during distribution which may indicate network integrity issues, such as increased turbidity levels, low residual chlorine or pH changes.

Control measures in the distribution network may be specific to a particular location (for example, a secondary or booster chlorination station or a pressure reducing valve) or they may be non-specific and span the network in general (such as maintenance of an adequate residual chlorine concentration or a mains cleaning programme). Where specific control measures exist, operational monitoring should be performed at this particular location in the distribution network. For operational monitoring of non-specific control measures, representative sample points for water quality testing should be selected throughout the entire distribution network. Guidance on choosing appropriate water quality sample point locations in a distribution network is presented in Textbox G.

Table 20. *Examples of generic control measures in distribution systems alongside corresponding operational monitoring*

Example control measures	Example of corresponding operational monitoring
Maintenance of sufficient residual chlorine concentration	• Residual chlorine concentration (M)
Secondary (booster) chlorination	• Residual chlorine concentration (M)
Asset maintenance programme	• Asset integrity inspections (V)
Mains cleaning programme	• Turbidity; residual chlorine concentration (M)
Unaccounted water recovery programme (e.g. through minimization of water leakages, illegal connections)	• Volumetric monitoring of unaccounted water (M)
Mains installation/repair procedures	• Field check of mains installation/repair work (V)
Backflow prevention device inspection programme	• Backflow device testing (V)
Valves (pressure reducing, non-return)	• Asset performance/condition inspection (V)
Use of materials in the distribution system suitable for contact with drinking-water (e.g. fittings, valves, pipe material)	• Check purchasing policy compliance (V) • Check certificates of compliance to the appropriate manufacture standards (V)
Optimizing treated water pH to minimize corrosion	• pH monitoring (M) • Corrosion by-products monitoring (e.g. iron, lead, copper, zinc [M]) • Asset condition inspection (V)
Maintenance of positive pressure in the distribution network	• Monitoring and recording of network pressures (M)
Site/asset security (e.g. locks on valves)	• On-site security inspections (V)
Standard operating procedures for distribution activities	• Field check of compliance with relevant SOP (V)

V – visual; M – measurable.

(G) Choosing the location of water quality sample points in a distribution network

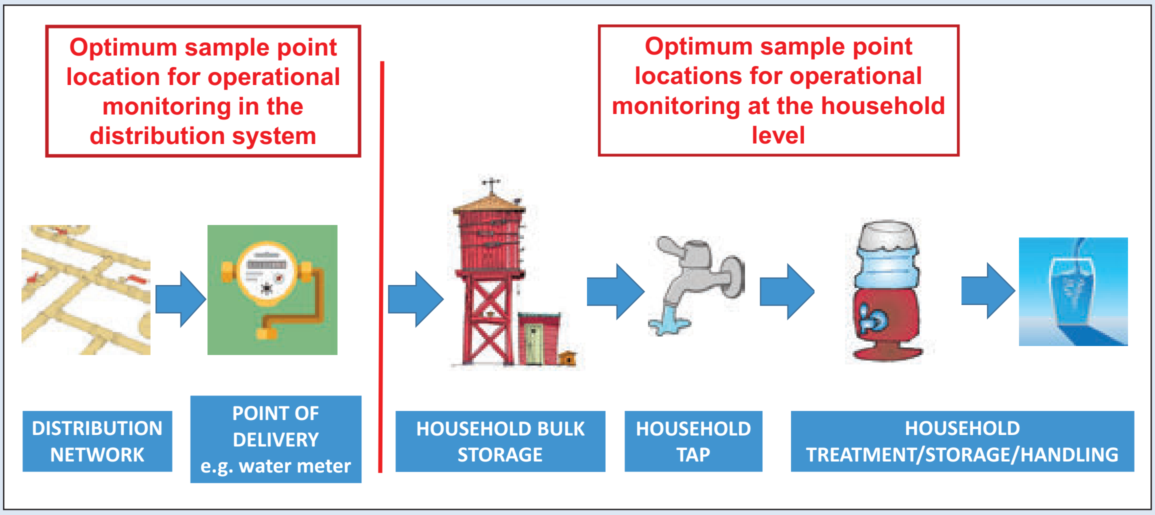
Sample points for operational monitoring water quality testing in the distribution system should be selected to represent the entire network, ensuring that they:

- represent the start, middle and end of the distribution system
- target known water quality trouble spots (for example, low flow/pressure areas, low-usage areas or areas where historical monitoring has detected water quality issues)
- target vulnerable customer locations (for example, aged care facilities, schools, and hospitals).

The physical sample point should be in a sanitary location (to avoid the risk of contaminating the sample during collection) that is easily and safely accessible by the person collecting the water sample.

Due to the potential for deterioration in water quality through poor customer water storage and handling practices, sample points for operational monitoring within the distribution system should ideally be located at the point of delivery before consumer storage/handling (for example, at the water meter or standpipe; Figure 9). This will ensure the water quality results are representative of the water being supplied to the consumer irrespective of consumer practices. For example, an operational monitoring sample taken at the consumer tap after storage in a household bulk storage tank may have high turbidity due to contamination present in the household bulk storage tank (e.g. accumulated sediment from a lack of cleaning), and not as a result of the failure of an upstream control measure in the distribution system (e.g. insanitary pipe repair job). In this example, the poor water quality result may trigger unnecessary corrective actions (for example, cleaning/flushing distribution mains), that are unrelated to the actual cause of the issue (that is, an insanitary consumer bulk storage tank). Water quality sampling after consumer storage and handling is appropriate for operational monitoring at the household level (see Section 2.2.2.5) or public health surveillance.

Figure 9. *Process flow diagram illustrating the optimum water quality sample point location for operational monitoring in the distribution system*



The number of water quality sample points required for a distribution network, and the frequency at which they are sampled, will vary depending on the size and complexity of the network and the corresponding risks identified for that system. An example of the frequency of water quality testing is presented in Table 21, but this should be considered in the context of the specific situation.

Table 21. *Example on the minimum frequency of water quality testing for operational monitoring in a distribution system*

Population size	Minimum number of sample points to be tested per week
< 5 000	3
> 5 000	1 additional sample point per 5 000 of population

An operational monitoring sampling schedule should be developed, which describes the sample point locations that are to be tested each week. Where possible, the sampling schedule should be developed such that:

(7) weekly sample point locations are representative of the start, middle and end of the distribution network; and

(8) different sample points are visited each week.

Sampling schedules should take care to consider the particular circumstances of the water supply system. Such as in cases where intermittent supply is in place and water may be unavailable for sampling purposes during particular periods (e.g. when water is supplied only on alternate days).

Textbox H illustrates the selection of sample point locations and the development of a sampling schedule for the example water supply system. Table 25 describes the OMP for the distribution system, based on the control measures identified in Table 9.

(H) Water quality sample point selection and sampling schedule in the distribution network: Example water supply system

Based on the population size of the example water supply system (i.e. < 5 000), three sample points per week are to be tested. A total of 12 sample points were identified for water quality testing, which allows all 12 locations to be sampled in a one-month period (i.e. different three locations each week). Based on the guidance presented above, Figure 10 illustrates the location of the sample points throughout the example distribution network.

Figure 10. *Location of sample points for operational monitoring water quality testing in the example distribution system; sample points are presented in red*

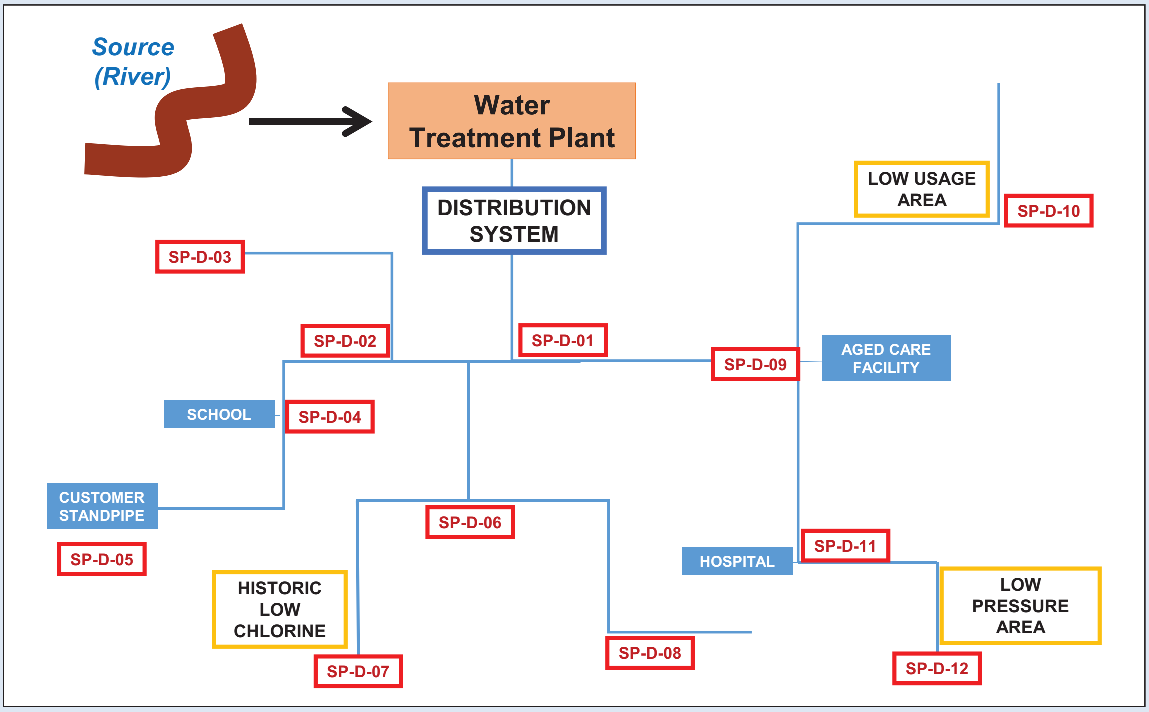


Table 22. *Sample point selection and water quality testing for operational monitoring in the distribution system*

Sample point code	Sample point description	Minimum recommended testing	Purpose for selection
SP-D-01 to SP-D-12	As per Table 23	• Chlorine • pH • Turbidity	• May provide indication of water quality deterioration during distribution • May indicate network integrity issue (e.g. burst, leak, illegal connection) • May provide early warning for potential downstream customer impacts

(H) Water quality sample point selection and sampling schedule in a distribution network: Example water supply system…continued

The monthly sampling schedule for operational monitoring water quality testing in the example water supply system is given in Table 23.

Table 23. *Monthly sampling schedule for water quality testing in the distribution system*

Week number	Sample point code	Sample point description
1	SP-D-01	No. 4, Shop Street
	SP-D-09	No. 90, Shop Street (Aged care facility)
	SP-D-07	No. 8, Niainin Row
2	SP-D-02	No. 21, Market Square
	SP-D-06	No. 6, School Street
	SP-D-05	School Street customer standpipe
3	SP-D-04	No. 31, School Street (Primary School)
	SP-D-08	No. 71, Market Street
	SP-D-03	Lot No. 41, Monahan Close
4	SP-D-10	Lot No. 111, Corner Street
	SP-D-11	No. 34, Hospital Street (Hospital)
	SP-D-12	No. 123, Howard Close

Table 25. *OMP for the distribution system for the example water supply system*

Control measure	OPERATIONAL MONITORING					Critical limit	Corrective action Consider situation and decide on the most appropriate response:
	Where?	What?	How?	When?	Who?		
Process step: Distribution							
Asset integrity inspection programme	Distribution network	Inspect integrity and performance of assets (pipes, valves, fittings, water meters)	• Visual inspection of asset integrity • Testing of operation and performance	As per asset maintenance schedule (based on asset criticality and age)	Network maintenance team	• Failure of performance test • Identification of integrity issue (e.g. leak, break)	• Repair or replace affected asset as required
Mains cleaning programme	Distribution sample points (SP-D-01 to SP-D-12)	Turbidity in distribution water	Turbidity tube	3 sample points per week (from different locations)	Technician	> 5 NTU	• Review water quality trends and network operations to investigate source of turbidity • If dirty mains suspected, clean affected section of mains • Flush the affected water from the distribution network
Maintenance of sufficient residual chlorine concentration	Distribution sample points (SP-D-01 to SP-D-12)	Residual chlorine concentration in distribution system	Residual chlorine analyser	3 samples per week (from different locations)	Technician	< 0.2 mg/L > 1.0 mg/L	• Optimise the chlorine dose at the water treatment facility • If low chlorine levels detected: - assess the need to clean mains - check for network integrity issues (e.g. leak, break) - assess if hydraulic regime is optimised to minimise water age • Flush affected water from the mains until acceptable chlorine levels detected If disinfection is thought to be compromised, undertake immediate water quality testing to determine the impact and appropriate action

Control measure	OPERATIONAL MONITORING					Critical limit	Corrective action Consider situation and decide on the most appropriate response:
	Where?	What?	How?	When?	Who?		
Maintenance of sufficient residual chlorine concentration … continued	Distribution sample points (SP-D-01 to SP-D-12)	pH in distribution system water	pH meter	3 samples per week (from different locations)	Technician	pH < 6.5 pH > 8.5	• Review water quality trends and network operations to investigate source of pH change: - if pH is suboptimal entering the distribution system, adjust pH at the water treatment plant - if pH is low due to long water age (e.g. low usage), flush the affected mains and optimise the hydraulic regime for this section
Backflow prevention devices	On-site	• Presence of device where required • If present, device performance	• Site visit for visual inspection and testing of devices	On-going inspection programme; 5 properties per month	Plumbing technician	• Absence of testing device where required or failure of performance testing	• Install device as required • Replace faulty devices as required
Plumbing inspection programme	On-site	Inspect network for the presence of illegal or cross connections	Site visit and visual inspection	On-going inspection programme; 5 properties per month	Plumbing technician	Detection of illegal or cross connections	• Disconnect non-compliant connections
Routine standpipe inspection programme	On-site	Inspect standpipe integrity and sanitary condition	Site visit and visual inspection of standpipes	On-going monthly inspection programme	Network maintenance team	Detection of insanitary or faulty standpipe	• Repair integrity issues • Restore sanitary conditions

Control measure	OPERATIONAL MONITORING					Critical limit	Corrective action Consider situation and decide on the most appropriate response:
	Where?	What?	How?	When?	Who?		
Procedures for new mains installation or repair	On-site during works	Field check of adherence to procedure	On-site during mains repair/ replacement	During mains repair/ replacement	Network maintenance team	Deviation from procedure impacting water quality	• Staff retraining and competency assessment If water quality is thought to be compromised, flush the affected section of the network and undertake immediate water quality testing to determine the extent and appropriate action
	On-site during works	Water quality monitoring following completion of works: - turbidity - residual chlorine - pH	• Turbidity tubes • Chlorine analyser • pH meter	Following completion of works	Technician	Turbidity: > 5 NTU Residual chlorine: < 0.2 mg/L > 1.0 mg/L pH: pH < 6.5 pH > 8.5	

Define operational monitoring at the household level

Although not always directly under the responsibility of the water supplier, effective water safety planning must consider consumer practices beyond the point of consumer delivery (that is after the water meter, standpipe or beyond the consumer property boundary). Water quality risks at the household level may arise from inadequate compliance to plumbing standards (for example, backflow, cross connections, illegal connections, corrosion issues related to inappropriate internal pluming materials), ineffective household water treatment practices and/or poor household water storage and handling practices. Although the water supplier may not be held responsible for the deterioration in water quality beyond the point of delivery, they may play an important role in consumer awareness and education to ensure that drinking-water remains safe through to the point of human consumption. Appropriate, external support may be required for development of an OMP at the household level, for example, from public health officials, community leaders and/ or non-governmental organizations.

Household water treatment and safe storage (HWTS) is an important component within the WSP framework to maintain and/or improve drinking-water quality, where continuous access to safe water delivered directly to the home is not possible. Although it is not a substitute for safe and continuous water service to the home, HWTS is an effective interim measure to ensure safe drinking-water at the household level[18].

Table 26 provides some examples of control measures at the household level, alongside examples of operational monitoring that may be applied to these control measures to ensure they are performing acceptably.

Table 26. *Examples of generic control measures at the household level alongside corresponding operational monitoring*

Example control measures	Example of corresponding operational monitoring
Plumbing standards/codes of practice	• Compliance check (V)
Household plumbing inspection programme	
Community HWTS education	• Field check of HWTS practices (V) • Monitoring of household water quality (post-treatment, storage and/or handling; M)

V – visual; M – measurable.

Water quality testing at the household level should ideally be immediately before the point of consumption by the consumer (that is, post household treatment, storage and/or handling; Figure 9). To evaluate the appropriateness of household-level practices, water quality testing results from the household should be compared to the water quality at the point of delivery (for example, at the consumer water meter) to see if water quality deteriorates during household water treatment, storage and/or handling. If water quality issues are detected prior to the point of consumption, follow-up investigations may target more specific sample locations, for example, taking individual samples post-household treatment, post-storage and/or post-consumer handling to determine exactly where the water quality issue occurs along the HWTS chain.

18 World Health Organization (2013). *Household Water Treatment and Safe Storage: Manual for the Participant*. World Health Organization. Geneva, Switzerland.

Textbox I describes, water quality testing sample point identification for operational monitoring at the household level in the example water supply system. Table 28 describes the OMP at the household level, based on the control measure identified in Table 10.

(I) Operational monitoring at the household: Example water supply system

For the example water supply system, two water quality testing sample points have been identified for operational monitoring at the household level, the details of which are presented in Figure 11 and Table 27.

Figure 11. *Process flow diagram illustrating the water quality testing sample point locations for operational monitoring at the household level*

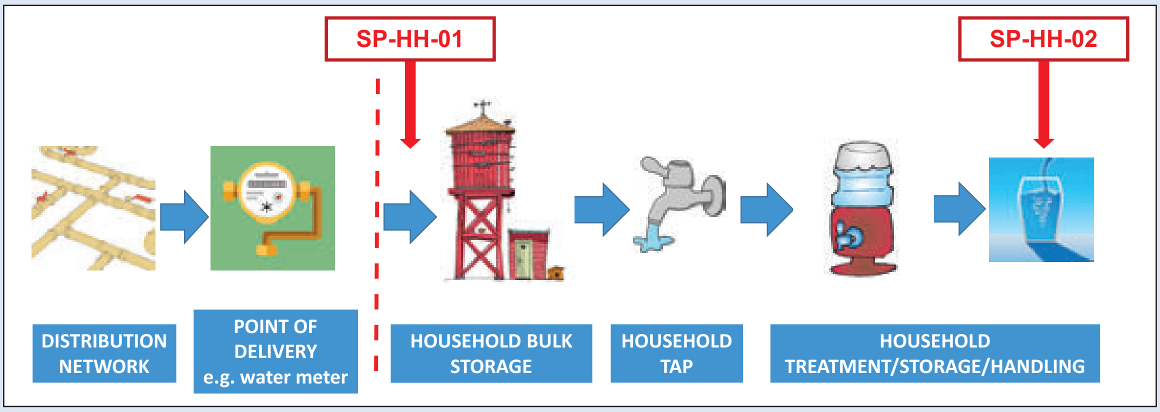


Table 27. *Sample point selection and water quality testing for operational monitoring at the household level*

Sample point code	Sample point description	Minimum recommended testing	Purpose for selection
SP-HH-01	Water meter (including property address)	• Chlorine • pH • Turbidity	• May provide indication of water quality deterioration as a result of household water treatment, storage and/or handling practices
SP-HH-02	Post household handling (including property address)		

Table 28. OMP at the household level for the example water supply system

Control measure	OPERATIONAL MONITORING					Critical limit	Corrective action Consider situation and decide on the most appropriate response:
	Where?	What?	How?	When?	Who?		
Process step: Household							
Education and awareness programme for appropriate household water treatment, storage and handling practices	On-site in consumer household	Appropriate household water treatment, storage and/ or handling in practice	Visual inspection in consumer premises	One household per month (selected at random)	Water quality liaison officer	Observation of inappropriate household water treatment, storage and/ or handling practices	• Advise households on appropriate practices
	• Household water meter (or equivalent) (SP-HH-01) • Post household handling (immediately before consumption) (SP-HH-02)	• Turbidity • Residual chlorine • pH	• Turbidity tubes • Chlorine analyser • pH meter	One household per month (selected at random from the community)	Water quality liaison officer	<u>Turbidity:</u> > 5 NTU <u>Residual chlorine:</u> < 0.2 mg/L > 1.0 mg/L <u>pH:</u> pH < 6.5 pH > 8.5	• Investigate source of deterioration in water quality: - if insanitary bulk storage tank suspected, advise consumer to clean tank - if insanitary storage container or handling utensil suspected, advise consumer to replace with appropriate item - if suboptimal/ineffective treatment suspected (e.g. suboptimal chlorine dosing, boiling, filter components damaged/ in need of replacement), advise consumer on effective treatment practices and/or maintenance regimes

Step 3: Implement the operational monitoring plan

Once the OMP has been developed and documented, the necessary water quality testing equipment has been acquired, and the individuals responsible for carrying out the operational monitoring have received appropriate training, the OMP is ready to be implemented.

It is the responsibility of the designated person (i.e. the Who?) to ensure that all operational monitoring is performed according to the OMP, and, in the event of a critical limit breach, that appropriate corrective action is taken in a timely fashion.

It is the responsibility of the supervisor to routinely review the operational monitoring data, to ensure that the operational monitoring and corrective actions are being performed according to the OMP.

Operational monitoring plan log sheets

To assist operational staff to perform operational monitoring as part of their routine duties, operational monitoring log sheets should be developed. These may serve the purpose of providing:

(1) clear guidance for the operational staff on the type and frequency of operational monitoring that need to be completed;

(2) a record of water quality testing results for historical water quality trending; and

(3) a record of operational monitoring activities for WSP auditing and verification purposes.

The logged data used for developing historical water quality trends (for example, establishing seasonal water quality patterns) may also assist with setting appropriate and effective critical limits.

To assist operational staff with completing the operational monitoring as per the OMP, log sheets should contain the following information:

(1) the sample point code and description;

(2) the check to be performed;

(3) the frequency at which the check should be performed; and

(4) the corresponding critical limit.

It is important to include the critical limit on the log sheet, so the individual responsible for performing the operational monitoring can clearly see when a critical limit has been breached and when corrective action is required. The OMP may then be consulted to determine what corrective action must be taken.

A template operational monitoring plan log sheet for water quality testing within the example water supply system is provided in Table 29. Similar log sheets may also be developed for the operational monitoring visual inspections.

Table 29. *Operational monitoring log sheet for the example water supply system: Source and water treatment plant*

3xD = 3 TIMES DAILY D = DAILY W = WEEKLY M = MONTHLY	*Operational Monitoring Results Log Sheet*															
	SOURCE		WATER TREATMENT PLANT													COMPLETED BY:
DATE/TIME	RAW WATER PRE-SEDIMENTATION CHANNEL (SP-S-01)	RAW WATER POST-SEDIMENTATION CHANNEL (SP-S-02)	PLANT INLET (PRE-ALUM DOSE) (SP-WTP-01)		SEDIMENTATION TANK INLET (POST-ALUM DOSE) (SP-WTP-02)	SEDIMENTATION TANK 1 OUTLET (SP-WTP-03)	SEDIMENTATION TANK 2 OUTLET (SP-WTP-04)	FILTER 1 OUTLET (SP-WTP-05)	FILTER 2 OUTLET (SP-WTP-06)	TREATED WATER TANK INLET (SP-WTP-07)		TREATED WATER TANK OUTLET (SP-WTP-08)				
	TURBIDITY (NTU)^{D}	TURBIDITY (NTU)^{D}	TURBIDITY (NTU)^{D}	pH^{D}	pH^{D}	TURBIDITY (NTU)^{D}	TURBIDITY (NTU)^{D}	TURBIDITY (NTU)^{3xD}	TURBIDITY (NTU)^{3xD}	CHLORINE (mg/L)^{D}	pH^{D}	pH^{D}	TURBIDITY (NTU)^{D}	CHLORINE (mg/L)^{3xD}		
CRITICAL LIMIT	> 1 000 Dry Season > 2 000 Wet Season	> 100 Dry Season > 500 Wet Season	> 100 Dry Season > 500 Wet Season	< 6.5 > 8.0	< 6.5 > 8.0	> 50	> 50	> 5	> 5	< 0.5 > 2.0	< 6.5 > 8.5	< 6.5 > 8.5	> 5	< 0.5 > 2.0		

Step 4: Review the operational monitoring plan - revise as necessary

Once a new OMP has been established, and water quality data begins to be collected, careful review of the operational monitoring data is required to ensure the OMP is appropriate.

Over time, operational monitoring data trends will be established which will determine:

- what is considered normal operation for the water supply system?
- what is considered to be a deviation from normal?
- what is considered a critical deviation from normal?
- are the corrective actions appropriate for the water supply system? and
- are existing control measures adequate, or are additional controls needed?

In the absence of historical water quality data, critical limits may often be set initially based on operational estimates or health/aesthetic guidelines values, which may not be appropriate in the context of the particular water supply system (i.e. too stringent or too lenient for the particular context). Where an OMP has been developed in the absence of historical water quality data, careful and regular review of the operational monitoring data is strongly recommended during the initial incubation period to ensure the OMP is appropriate and effective.

In addition to scheduled reviews (Module 10), operational data should be reviewed after water quality incidents and near-miss events as part of the post-incident review (Module 11; Figure 1). In light of water quality incidents, the effectiveness of existing critical limits, corrective actions and control measure performance should be reviewed, to ensure they are appropriate to manage water quality risk within the water supply system.

Case Study: Operational Monitoring Plan Development in Bhutan

1. Background

Following the introduction of WSPs to Bhutan, operational monitoring was recognised as a key area for development within the pilot water supply systems. Accordingly, a supporting programme for operational monitoring was developed and delivered in 2014 in one pilot water supply system (namely, Wangdue) for future scale-up to the remaining four pilot water supply systems.

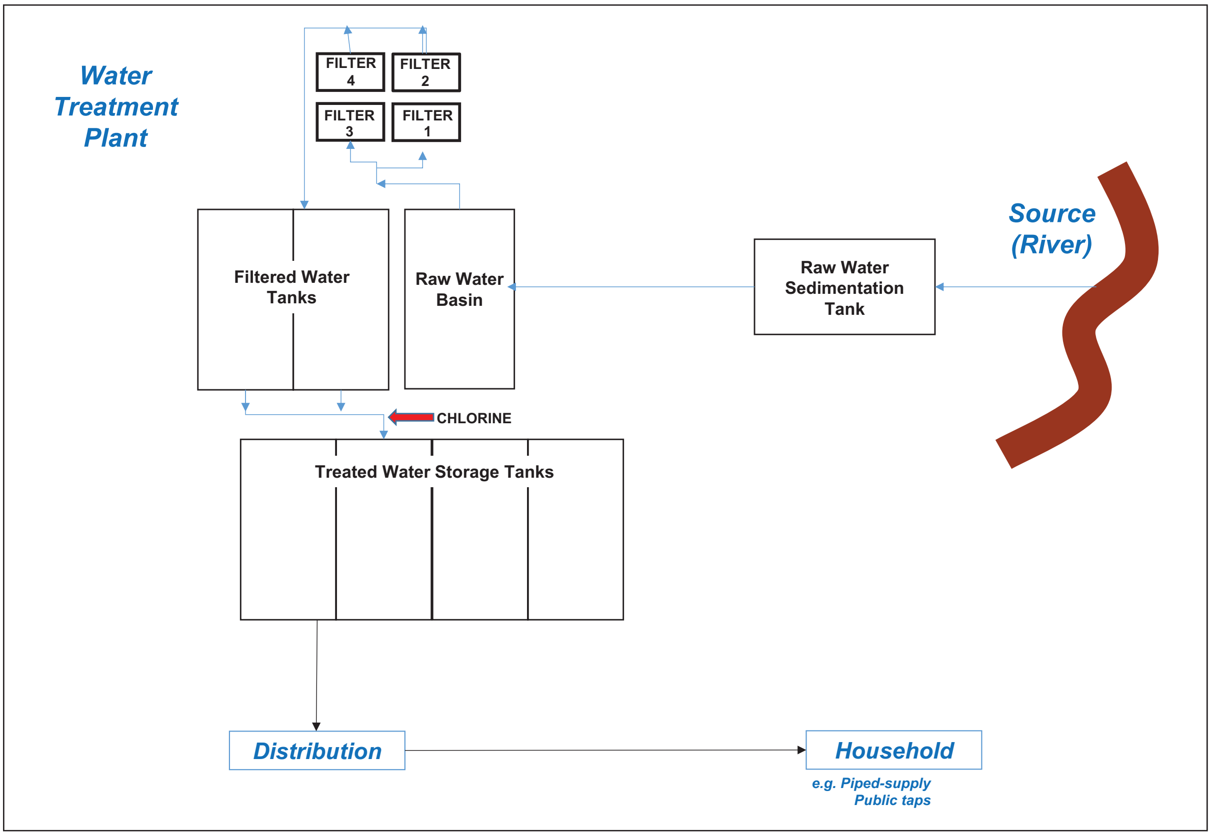
2. Water supply system information

The system description for Wangdue water supply system is provided in Table A1, alongside a simplified process flow diagram (Figure A1).

Table A1. *Water supply system characteristics for Wangdue*

Population served:	Approximately 5 000
Source water:	Surface water (river)
Climate characteristics:	Dry season/wet season
System description:	**Source:** • Raw water sedimentation tank **Water Treatment Plant (2 600 m^3/day):** • Raw water basin • Rapid sand filtration (2 sets of 2 filter units operating in parallel) • Disinfection (chlorination) • Treated water storage (4 interconnected tanks; on-site at water treatment facility) **Distribution:** • Household piped water supply; public taps **Household:** • Household bulk storage, water treatment (filtration and/or boiling) and storage post-household treatment
Key water quality challenges:	• Seasonal source water quality (high turbidity during wet season) • Run-off from human settlements, agriculture and light industry within the catchment upstream of the raw water off-take • Intermittent supply (limited water treatment plant capacity) • Unaccounted water (leakages; illegal connections)

Figure A1. *Simplified process flow diagram of Wangdue water supply system*



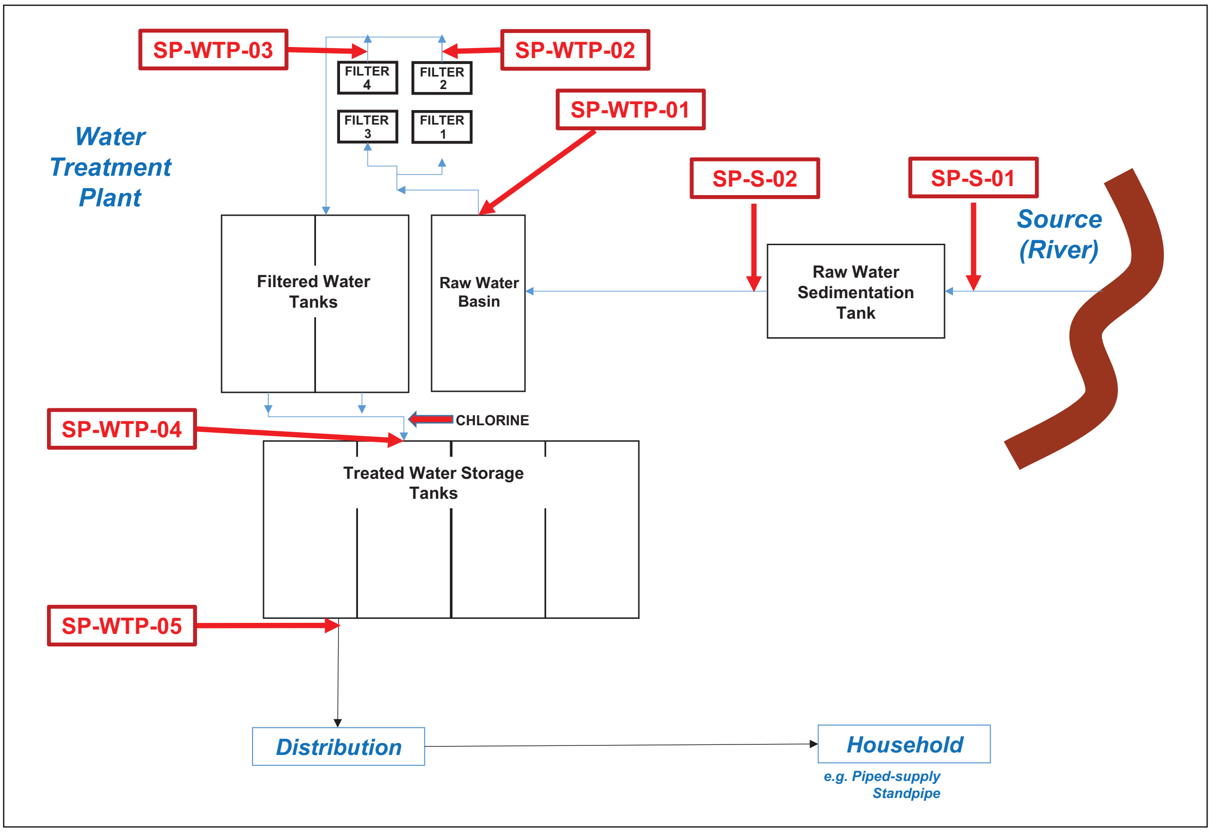
3. Sample point identification

Based on the existing control measures identified within the water supply system, appropriate sample point locations were selected for operational monitoring water quality testing. The sample points selected are listed in Table A2, and graphically illustrated in Figures A2 and A3.

Table A2. *Sample point selection for operational monitoring water quality testing in Wangdue water supply system*

Sample point code	Sample point description	Parameter monitored	Purpose for selection
SP-S-01	Sedimentation tank inlet	• Turbidity	• Monitoring of raw water (river) quality • Monitoring of sedimentation process • May indicate tank integrity issues • May indicate when tank requires cleaning • May inform the decision to cease raw water harvesting (selective harvesting)
SP-S-02	Sedimentation tank outlet	• Turbidity	
SP-WTP-01	Raw water basin outlet	• Turbidity • pH	• May provide early warning for potential downstream water quality impacts • May indicate when basin requires cleaning • May indicate raw water main integrity issues (e.g. raw water main break)
SP-WTP-02	Filter 2 outlet	• Turbidity	• Monitoring and optimization of each individual bank of 2 filters • May trigger optimization of upstream processes (e.g. sedimentation) • May provide early warning for potential downstream treatment issues • Note: Sampling of Filter 1 and/or 3 should occur following effluent quality issues from Filter 2 and/or 4
SP-WTP-03	Filter 4 outlet	• Turbidity	
SP-WTP-04	Treated water tank inlet	• Chlorine • pH • Turbidity	• Monitoring and optimization of chlorination • May indicate when filtered water tanks require cleaning
SP-WTP-05	Treated water tank outlet (entry point to the water supply system)	• Chlorine • pH • Turbidity	• Monitoring and optimization of chlorination • Verification of the final water quality prior to supply to consumers (i.e. may trigger optimization of upstream treatment processes) • May indicate tank integrity issue • May indicate when tank cleaning is required
SP-D-01 **to** **SP-D-12**	Distribution sample points (12 in total; see Table A3 and Figure A3)	• Chlorine • pH • Turbidity	• Monitoring of water quality through to the point of consumer delivery • May detect network integrity issues (e.g. leaks, bursts, illegal connection) • May indicate when mains cleaning is required

Figure A2. *Graphical illustration of sample point distribution for the source and water treatment plant in Wangdue water supply system*



Twelve sample point locations were selected in the distribution system, representing the start, middle and end of the system. As the town of Bajo represented the largest population centre in Wangdue water supply system, four sample point locations were selected throughout the town (Figure A3). The sampling schedule was developed such that one sample from Bajo town was to be taken each week, and all 12 sample points were to be sampled within a one-month period. Vulnerable populations were also represented, including the schools and the hospital (see Table A3).

Figure A3. *Approximate sample point locations in Wangdue distribution system*

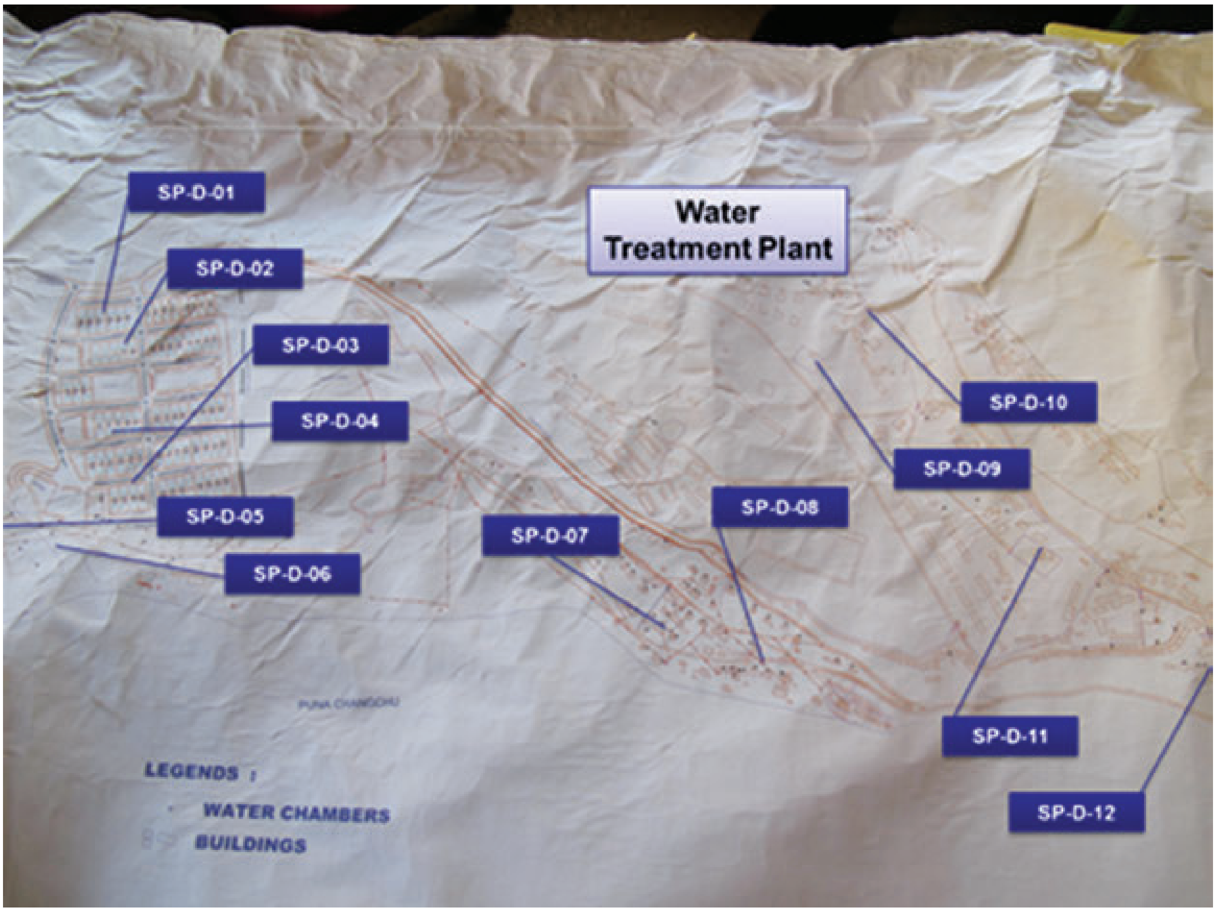


Table A2 describes the monthly sampling schedule for operational monitoring water quality testing in Wangdue distribution.

Table A3. *Sampling schedule for Wangdue distribution system water quality testing*

Week number	Sample point code	Sample point description
Week No. 1	SP-D-01	Plot no. 111 Bajo Town
	SP-D-07	RNRC PD Residence (Lower Market)
	SP-D-10	Tencholing Primary School
Week No. 2	SP-D-02	Plot no. 58 Bajo Town
	SP-D-09	Tencholing Family Residence
	SP-D-12	Dratsang
Week No. 3	SP-D-03	Plot no. 2 Bajo Town
	SP-D-06	Bajo Hospital
	SP-D-08	RBP Colony (Lower Market)
Week No. 4	SP-D-04	Plot no. 27 Bajo Town
	SP-D-05	Bajo High School
	SP-D-11	Wangdue Lower Secondary School

The OMP for water quality testing in Wangdue water supply system is presented in Table A4.

Table A4. *Wangdue OMP: Water quality testing*

Process step	OPERATIONAL MONITORING					Critical limits	Corrective actions if critical limits exceeded Consider and decide most appropriate response:
	WHERE?	WHAT?	HOW?	WHEN?	WHO?		
Source	Sedimentation tank inlet (SP-S-01)	Turbidity	Turbidity meter	Monthly *(Weekly Monsoon)*	Municipal Technician	Not applicable	(Sedimentation tank inlet turbidity tested only for comparison with outlet turbidity to measure turbidity reduction achieved through sedimentation tank.)
	Sedimentation tank outlet (SP-S-02)	Turbidity	Turbidity meter	Monthly *(Weekly Monsoon)*	Municipal Technician	> 500 NTU *(> 1 000 NTU Monsoon)*	• Suspend raw water harvesting until turbidity drops below critical limit • Clean sedimentation basin • Reduce flow rate to increase retention time
Water treatment plant	Raw water basin outlet (SP-WTP-01)	Turbidity	Turbidity meter	Daily	Municipal Technician	> 500 NTU *(> 1,000 NTU Monsoon)*	• Suspend raw water harvesting until turbidity drops below critical limit • Clean raw water basin • Reduce flow rate to increase retention time
		pH	pH meter	Weekly	Municipal Technician	pH < 6.5 or > 8.5	• Source of pH change to be investigated
	Filter 2 outlet (SP-WTP-02)	Turbidity	Turbidity meter	Daily	Municipal Technician	> 5 NTU	• Investigate source of turbidity • Initiate backwash of filter • If this does not resolve the issue, consider reducing flow rate through the plant
	Filter 4 outlet (SP-WTP-03)	Turbidity	Turbidity meter	Daily	Municipal Technician	> 5 NTU	
	Treated water tank inlet (SP-WTP-04)	Turbidity	Turbidity meter	Daily	Municipal Technician	> 5 NTU	• Initiate backwash of filter • Investigate if filtered water basin requires cleaning and maintenance (sediment removal) • If this does not resolve the issue, check upstream turbidity and consider reducing flow rate through the plant
		Residual chlorine	Chlorine meter	Daily	Municipal Technician	< 0.8 mg/L > 1.5 mg/L	• Confirm correct chlorine dose is being applied; Increase or decrease chlorine dose as required Confirm chlorine pump(s) operating optimally Confirm chlorine batch prepared correctly according to SOP

Process step	OPERATIONAL MONITORING					Critical limits	Corrective actions if critical limits exceeded Consider and decide most appropriate response:
	WHERE?	WHAT?	HOW?	WHEN?	WHO?		
Water treatment plant... continued	Treated water tank outlet (SP-WTP-05)	pH	pH meter	Weekly	Municipal Technician	pH < 6.5 pH > 8.5	• Confirm correct chlorine dose is being applied • Source of pH change to be investigated
		Turbidity	Turbidity meter	Daily	Municipal Technician	> 5 NTU	• Filter operation to be investigated; Initiate backwash of filter if required • Check for leaks/breaks in pipeline or damage to basin roof • Investigate if basin requires cleaning and maintenance (sediment removal) • Water treatment plant performance and upstream water quality trends to be reviewed
		Residual chlorine	Chlorine meter	Daily	Municipal Technician	< 0.5 mg/L > 0.9 mg/L	• Confirm correct chlorine dose is being applied; Increase or decrease chlorine dose as required • Confirm chlorine pump(s) operating optimally • Confirm chlorine batch prepared correctly according to SOP • Water treatment plant performance and upstream water quality trends to be reviewed

Process step	OPERATIONAL MONITORING					Critical limits	Corrective actions if critical limits exceeded Consider and decide most appropriate response:
	WHERE?	WHAT?	HOW?	WHEN?	WHO?		
Distribution system	Consumer tap (SP-D-01 to SP-D-12)	pH	pH meter	3 sites per week	Municipal Technician	pH < 6.5 pH > 8.5	• Source of pH change to be investigated • Water treatment plant performance and upstream water quality trends to be reviewed
		Turbidity	Turbidity meter	3 sites per week	Municipal Technician	> 5 NTU	• Check for leaks/breaks in pipeline and any other potential sources of contamination • Water treatment plant performance and upstream water quality trends to be reviewed • Filter operation may need to be optimized at water treatment plant • Additional water quality tests to be performed in the area to determine the extent of the problem • Flushing of water mains may be required if the problem is isolated to a particular section
		Residual chlorine	Chlorine meter	3 sites per week	Municipal Technician	< 0.2 mg/L > 0.6 mg/L	• Confirm correct chlorine dose is being applied; Increase or decrease chlorine dose as required • Water treatment plant performance and upstream water quality trends to be reviewed • Additional water quality tests to be performed in the area to determine the extent of the problem • Flushing of water mains may be required if the problem is isolated to a particular section

Notes:

1. The OMP for the visual operational monitoring parameters was developed separately, and is not shown here.

2. Subsequent revision and incremental improvement of the Wangdue WSP integrated HWTS into the WSP in 2014; this revision recommended identified additional HWTS-related risks and corresponding control measures, including household awareness and education training, with corresponding operational monitoring achieved through routine household visits and water quality testing.

Glossary of Terms

Abstraction (in reference to drinking-water): The process of harvesting raw (untreated) water for drinking-water supply.

Aesthetic (in reference to drinking-water quality): Relates to the taste, odour or appearance of drinking-water.

Backflow: The unintentional flow of contaminated water in the reverse direction to normal drinking-water flow.

Chlorine decay: The decrease in chlorine concentration as water passes through a water supply system due to the reaction between chlorine and organic and/or inorganic materials.

Chlorine demand: The extent of reaction between chlorine and organic and/or inorganic material present in water that consumes chlorine and results in a decrease in the chlorine concentration.

Chlorine disinfection: The addition of chlorine to drinking-water, inactivate or kill microorganisms present in drinking-water; also referred to as chlorination.

Coagulation: Part of the water treatment process where a chemical (a coagulant) is added to water to assist with the removal of organic and inorganic materials (for example, clay, microorganisms, dissolved organic material).

Compliance monitoring: The testing of drinking-water to ensure that it meets water quality standards.

Contact time: The amount of time required for contact between chlorine and drinking-water for effective disinfection.

Control measure: A measure in place within a water supply system to prevent or eliminate a water safety hazard, or reduce it to an acceptable level.

Corrective actions: Timely action that may be taken to restore effective operation to a control measure once a critical limit has been exceeded.

Critical limit: The point at which a control measure is no longer deemed to be working effectively and a potential water quality risk exists.

Cross connections: The unintentional connections between drinking-water pipes and non-drinking-water pipes (such as sewerage or recycled water pipes).

Illegal connections: Unauthorised connections to the drinking-water supply pipes; illegal connections are often sources of leakages, and may introduce backflow or cross connections due to poor quality work or understanding of plumping risks.

Inorganic material: Any material that is not organic, for example, metals, minerals.

Intermediate storage: Treated drinking-water storage post-water treatment (for example, a reservoir or tank).

Jar test: A laboratory test where different concentrations of coagulant are added to a sample of water at different pH values to determine the optimum coagulant dose.

Operational monitoring plan: A document, which details all operational monitoring activities, critical limits and corrective actions.

Operational monitoring: Performance of simple, routine water quality checks that determines if a water supply system is operating within acceptable limits; operational monitoring checks the performance of control measures to ensure the supply of safe drinking-water.

Organic material: Material derived from the wastes and remains of organisms (such as plants and animals).

pH: Scale used to measure the acidity or alkalinity of water; the pH scale runs from pH 0 to pH 14, with pH 7 being neutral, $<$pH 7 being acidic and $>$pH 7 being alkaline (or basic).

Raw water off-take: The point at which raw (untreated) water is harvested for subsequent treatment and distribution.

Residual chlorine: The concentration of chlorine remaining in drinking-water after disinfection has occurred at the water treatment plant, which is available to protect the drinking-water from recontamination by microorganisms during distribution, through to the point of delivery to the consumer; also referred to as free chlorine.

Riparian buffer zone: Refers to a vegetated piece of land immediately adjacent to a water source, such as a river bank; the vegetated zone may act as a buffer, physically entrapping particles present in the water (such as sediment, nutrients, microorganisms), thereby reducing water quality impacts.

Secondary chlorination: The addition of chlorine to boost the residual chlorine concentration to within acceptable levels; generally occurs within the distribution system.

Source water: Raw (untreated) water for drinking-water supplies; includes groundwater, rainwater and various types of surface water sources, including rivers, lakes, ponds, creeks, irrigation channels, seawater or constructed reservoirs.

Turbidity: The opaque (or cloudy) appearance of water caused by the presence of organic and inorganic particles.

Water Safety Plan: Comprehensive, preventative drinking-water quality risk assessment and management approach, from the catchment through to the consumer.

The WHO/AusAID (DFAT) Partnership for Water Quality and Health has been promoting water safety plans (WSPs) in countries of the South-East Asia Region for more a decade. WSPs are designed to benefit all water users by ensuring improved water quality throughout a supply system and are seen as a way of improving health and enhancing system sustainability.

One of the biggest challenges for sustainable implementation of WSPs, especially for smaller systems, is good operational monitoring to ensure that control measures to improve water quality are still working.

WHO contracted an operational water quality expert to help Bhutan and Timor-Leste to improve their operational monitoring through the delivery of a tailored training programme and the implementation of standard operating procedures for using water quality monitoring instrumentation. These simple, clear and comprehensive SOPs are now published in response to a growing demand for supporting training materials and manuals for this technical area.

World Health Organization
Regional Office for South-East Asia
World Health House
Indraprastha Estate
Mahatma Gandhi Marg
New Delhi-110002, India

ISBN 978-92-9022-537-9